Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

PROJECT
MILE

PROJET
MPMP

DEMONSTRATION OF THE USE OF METHANOL IN LARGE ENGINES

PROJECT REPORT

CONTRACT SERIAL NO: 0S4 84-00421
CONTRACTOR: SYPHO-MUELLER
(PROJECT M I L E)

PROJECT MILE REPORT

A Report On The Use Of Methanol In Large Engines In Canada

Prepared for:

Energy, Mines and Resources Canada

by:

SYPHER:MUELLER International Inc.

161 pp

May 1990

91-02412/

ACKNOWLEDGEMENTS

Project MILE was intended to be a co-operative effort between government, vehicle fleet operators, engine and vehicle manufacturers, and the various supporting industries including fuel and lubricant suppliers, fuelling equipment manufacturers, etc. This intention was well and truly realized.

One of the great strengths of the project was the level of interest and support it generated in the people and organizations which it touched. MILE benefitted from the expertise and willing help of a wide range of companies and individuals involved in Canadian and U.S. bus and truck operations, alternative fuels investigation and vehicle emissions reduction.

SYPHER:MUELLER International Inc. wishes to acknowledge and thank all those who gave this valued assistance. In particular we thank those who participated in the regular Steering Committee meetings, and offered input which helped to maintain the topicality and currency of the project in the rapidly developing world of alternative vehicle fuels.

It is impossible to list all the individual contributors here.

The major participants included the following:

Canadian Oxygenated Fuels Association
The City of Medicine Hat Transit System
The City of Winnipeg Transit System
The City of Vancouver Equipment Management Branch
Williams Moving & Storage Ltd.
Caterpillar Incorporated
Cummins Engine Company
Detroit Diesel Corporation

We reiterate our thanks to all. The staff of SYPHER:MUELLER International Inc. are most pleased to have played a significant role in this comprehensive trial of a fuel which can make important contributions to Canadian energy self-sufficiency and a cleaner environment for all. We are sure that everyone concerned with MILE shares our satisfaction in this respect.

ABSTRACT

The Methanol In Large Engines (MILE) project was initiated in 1984 by the Canadian Federal Department of Energy, Mines and Resources. The project was a long-term trial of methanol fuelled compression-ignition engines in trucks and buses, operating in regular fleet service across Canada. The intention was to examine all aspects affecting the use of methanol as a fuel for a typical Canadian heavy vehicle fleet. The data and information gathered would then be used to make an assessment of the practical value of methanol as an alternative fuel for trucks and buses in the near to medium-term future. Methanol fuelled transit buses were tested in the cities of Winnipeg and Medicine Hat. Methanol heavy trucks operated in Vancouver, and on a long-distance run between Coquitlam and the Alberta-B.C. border. Each of the four participating fleets had two identical methanol vehicles, and these were matched against two similar diesel vehicles for performance comparison purposes. Each fleet was provided with a custom-built methanol fuelling station, appropriate safety equipment, personnel training, and repair and service backup, to support the trial program.

This report covers project activities up to October 1989. The methanol vehicles had covered almost 1,000,000 km in regular revenue earning fleet operations at that time. Vehicle operations are scheduled to continue until December 1990. A supplementary report will be issued to cover the balance of project work. In the early stages of the project many problems with engine reliability were uncovered. Continuing development by the engine manufacturers gave great improvements in all aspects of engine performance. The methanol vehicles were eventually able to match the corresponding diesel units in terms of power, driveability and monthly availability. Fuel consumption, on an energy content basis, did not equal diesel levels. Some mechanical problems remained unresolved, including fuel injector tip blockage, glow plug durability and valve seat wear. There were indications that long term bearing and cylinder wear would be as good as a diesel engine.

The participating fleets and supporting engine dealers were able to fuel, service and maintain the vehicles and engines without undue difficulty, although the requirement for outdoor fuelling would be a problem for a large transit bus fleet. The effect on servicing and repair work and safety measures was comparable to returning to the use of gasoline in heavy vehicles. The most prominent safety and health issues raised were the low visibility of a methanol flame, and the concentration of aldehyde group hydrocarbons in the engine exhaust gases.

Methanol fuelling could not compete economically against diesel, given the engine and methanol production technologies used during the project. A project study showed that possible large reductions in methanol production costs, coupled with increased prices of diesel engines, fuel and equipment necessary to realize future exhaust emissions standards, could make methanol cost effective in the future.

Project experience indicated that methanol is currently technically feasible as a heavy vehicle fuel. Engine performance and reliability is already acceptable, and will come very close to diesel standards in the near future. Methanol fuel can be used with little disruption to most normal vehicle servicing and operations procedures. Important exhaust emissions reductions are possible, including complete elimination of black smoke. At present methanol operation is more expensive, but future developments could eliminate the difference between overall diesel and methanol fleet costs.

The project was successful enough to cause the City of Medicine Hat to purchase three new methanol buses in late 1989. It will take delivery of three more in August, 1990, and will retain the two original project buses in service as part of a plan to convert the entire City transit fleet to methanol power.

TABLE OF CONTENTS

SECTION		PAGE
I	INTRODUCTION	I-1
	A. BACKGROUND TO PROJECT	I-1
	B. OBJECTIVES OF PROJECT	I-1
	C. SELECTION OF PARTICIPANTS	I-2
	D. INVOLVEMENT OF NEW YORK STATE	I-4
	E. OVERALL STATUS	I-4
II	OBJECTIVES	II-1
III	TECHNICAL	III-1
	A. FLEET VEHICLES	III-1
	B. VEHICLE CONVERSION	III-12
	C. FLEET FUELLING	III-25
	D. DATA COLLECTION	III-30
IV	OPERATIONS	IV-1
	A. WINNIPEG TRANSIT: FLYER/DDC BUSES	IV-1
	B. MEDICINE HAT TRANSIT: GMC/DDC BUSES	IV-20
	C. WILLIAMS MOVING & STORAGE: KENWORTH/ CATERPILLAR TRUCKS	IV-27
	D. CITY OF VANCOUVER: FREIGHTLINER/CUMMINS TRUCKS	IV-46
V	EMISSIONS	V-1
	A. BACKGROUND	V-1
	B. PROJECT EMISSIONS TESTING	V-2
	C. ALDEHYDE EMISSIONS TESTING	V-5
VI	FUEL FORMULATION	VI-1
	A. INTRODUCTION	VI-1
	B. FUEL PROPERTIES	VI-1
	C. FUEL MALODOURANT STUDY	VI-3
	D. FLAME LUMINOSITY	VI-3
	E. FUEL LUBRICITY	VI-5
	F. SUMMARY OF FINDINGS	VI-11
	G. RECOMMENDATIONS	VI-12

TABLE OF CONTENTS (Cont'd)

SECTION			PAGE
VII	LIFE CYCLE COSTS AND BENEFITS		VII-1
	A.	INTRODUCTION	VII-1
	B.	INCREMENTAL VEHICLE CAPITAL COSTS	VII-1
	C.	INCREMENTAL VEHICLE OPERATING COSTS	VII-4
	D.	INFRASTRUCTURE COSTS	VII-8
	E.	TOTAL INCREMENTAL COSTS	VII-9
	F.	EMISSIONS BENEFITS	VII-14
	G.	SUMMARY AND CONCLUSIONS	VII-19
VIII	BARRIERS TO COMMERCIALIZATION OF METHANOL		VIII-1
	A.	INTRODUCTION	VIII-1
	B.	OBJECTIVES	VIII-1
	C.	SELECTION OF FLEETS	VIII-1
	D.	DELIVERY OF SURVEY	VIII-1
	E.	SURVEY RESULTS	VIII-2
	F.	TECHNICAL BARRIERS	VIII-2
	G.	ECONOMIC BARRIERS	VIII-6
	H.	SOCIAL/ENVIRONMENTAL BARRIERS	VIII-8
	I.	CONCLUSIONS	VIII-10
IX	CONCLUSIONS		IX-1
	A.	STATE OF TECHNOLOGY	IX-1
	B.	VEHICLE PERFORMANCE	IX-2
	C.	FLEET INFRASTRUCTURE IMPACTS	IX-4
	D.	COSTS AND BENEFITS	IX-7

LIST OF FIGURES

FIGURE		PAGE
III-1	GMC Methanol Bus - Medicine Hat	III-4
III-2	Flyer Methanol Bus - Winnipeg	III-5
III-3	Kenworth Methanol Truck - Williams	III-6
III-4	Detroit Diesel 6V-92TA Methanol Engine	III-8
III-5	Caterpillar 3406 DITA Methanol Engine	III-9
III-6	Cummins L10 TA Methanol Engine	III-11
III-7	Detroit Diesel 6V-71N Diesel Installation (Flyer)	III-13
III-8	Detroit Diesel 6V-92TA Methanol Installation (Flyer)	III-13
III-9	Positive Locking "Dry-Break" Fuelling Connector	III-15
III-10	Emco-Wheaton "Dry-Break" Fuel system	III-15
III-11	Methanol Bus Fuel Cooler Unit	III-16
III-12	Electronic Control Box Location (Flyer)	III-16
III-13	Methanol Bus Electrical System Schematic	III-18
III-14	Methanol Bus Dash Panel Warning Lights	III-18
III-15	Fabricated Air Filter and Intake Cover (GMC)	III-19
III-16	Glow Plug Control Box and Fuel Cooled EDU	III-19
III-17	Fuel Filters and Electric Fuel Pump	III-20
III-18	DDEC Control Boxes Location (GMC)	III-20
III-19	Williams Moving & Storage Kenworth W900	III-22
III-20	RH Side of Caterpillar Engine Showing Extra Alternator	III-23
III-21	LH Side of Caterpillar Engine Showing Oil Reservoir	III-23
III-22	Stainless Steel Fuel Tank for Kenworth Methanol Truck	III-24
III-23	Kenworth Glow Plug Indicator Lights	III-24
III-24	City of Vancouver Methanol Truck	III-26
III-25	Cummins Methanol Engine	III-26
III-26	Cummins Engine Installation	III-27
III-27	Methanol Fuel Dispenser with Filter and "Dry-Break"	III-27
III-28	Schematic of Methanol Fuelling Station	III-31
III-29	Data Logger Unit Mounted in Bus	III-31
III-30	Electronic Data Collection Network	III-33
IV-1	Winnipeg Transit Flyer Methanol Bus	IV-2
IV-2	Cumulative Kilometers: Winnipeg Buses	IV-3
IV-3	Monthly Kilometers: Winnipeg Methanol Buses	IV-3
IV-4	Road Speed Profile: Winnipeg Buses	IV-4
IV-5	Engine Speed Profile: Winnipeg Buses	IV-4
IV-6	Monthly Fuel Consumption: Winnipeg Buses	IV-6
IV-7	Driveability Rating: Acceleration	IV-6
IV-8	Driveability Rating: Cold Starting	IV-13
IV-9	Driveability Rating: Hot Starting	IV-13
IV-10	Driveability Rating: Engine Idle	IV-14
IV-11	Driveability Rating: Over 50 km/hr	IV-14
IV-12	Driveability Rating: Under 50 km/hr	IV-16
IV-13	Driveability Rating: Transmission Shifting	IV-16
IV-14	Driveability Rating: Overall	IV-17
IV-15	Medicine Hat Transit Methanol Bus	IV-17
IV-16	Cumulative Kilometers: Medicine Hat Buses	IV-21
IV-17	Monthly Kilometers: Medicine Hat Buses	IV-21

LIST OF FIGURES (Cont'd)

FIGURE		PAGE
IV-18	Engine Speed Profile: Medicine Hat Buses	IV-22
IV-19	Road Speed Profile: Medicine Hat Buses	IV-22
IV-20	Monthly Fuel Consumption: Medicine Hat Buses	IV-24
IV-21	Williams Methanol Truck No.I-272	IV-26
IV-22	Cumulative Kilometers: Williams Trucks	IV-28
IV-23	Engine Speed Profile: Williams Trucks	IV-28
IV-24	Road Speed Profile: Williams Trucks	IV-29
IV-25	Monthly Fuel Consumption: Williams Trucks	IV-29
IV-26	Dynamometer Tractive Power: Caterpillar Trucks	IV-33
IV-27	Dynamometer Tractive Torque: Caterpillar Trucks	IV-33
IV-28	Dynamometer BSFC: Caterpillar Trucks	IV-34
IV-29	Exhaust Temperature: Caterpillar Trucks	IV-34
IV-30	Williams Methanol & Diesel Trucks	IV-35
IV-31	Iron Content of Engine Oil: Caterpillar	IV-36
IV-32	Methanol Engine Oil Analysis: Truck 289	IV-36
IV-33	Methanol Engine Oil Analysis: Truck 289	IV-38
IV-34	Methanol Engine Oil Analysis: Truck 272	IV-38
IV-35	Methanol Engine Oil Analysis: Truck 272	VI-39
IV-36	Diesel Engine Oil Analysis: Truck 203	IV-39
IV-37	Diesel Engine Oil Analysis: Truck 203	IV-40
IV-38	Diesel Engine Oil Analysis: Truck 205	IV-40
IV-39	Diesel Engine Oil Analysis: Truck 205	IV-41
IV-40	Driveability: Hot & Cold starting - Caterpillar	IV-43
IV-41	Driveability: Accln & Engine Idle - Caterpillar	IV-43
IV-42	Driveabilty: Over & Under 50 km/hr - Caterpillar	IV-44
IV-43	Driveability: Shifting & Overall - Caterpillar	IV-44
IV-44	City of Vancouver Methanol Truck	IV-47
IV-45	Cumulative Kilometers: City of Vancouver Trucks	IV-47
IV-46	Road Speed Profile: City of Vancouver	IV-48
IV-47	Engine Speed Profile: City of Vancouver	IV-48
IV-48	Monthly Fuel Consumption: City of Vancouver	IV-49
IV-49	City of Vancouver Methanol Dispenser	IV-53
V-1	Aldehyde Test Cart Schematic	V-6
VI-1	Lubricity Test Rig	VI-7
VI-2	Lubricity Test Rig	VI-7
VII-1	Vehicle Emissions Profiles	VII-16

LIST OF TABLES

TABLE		PAGE
III - 1	Project MILE Vehicles	III-2
III - 2	Project MILE Engines	III-3
IV - 1	Methanol Bus 601 Oil Analysis Results	IV-9
IV - 2	Methanol Bus 602 Oil Analysis Results	IV-9
IV - 3	Diesel Bus 603 Oil Analysis Results	IV-9
IV - 4	Diesel Bus 604 Oil Analysis Results	IV-9
IV - 5	Methanol Bus Oil Consumption	IV-11
IV - 6	Acceleration Times - Methanol and Diesel Buses	IV-11
IV - 7	Acceleration Times - Methanol 253 bhp Rating	IV-11
IV - 8	Fuel Consumption: Medicine Hat Buses	IV-24
IV - 9	Overall Fuel Consumption: Caterpillar Trucks	IV-31
IV - 10	Fuel Consumption: Cummins Trucks	IV-49
IV - 11	Oil Analysis Results: Cummins Trucks	IV-52
IV - 12	Engine Oil Consumption: Cummins Trucks	IV-52
IV - 13	Driveability Scores: Vancouver Methanol Truck	IV-53
V - 1	Emissions in Canada	V-1
V - 2	Summary of Heavy Duty Engine Emissions Regulations	V-2
V - 3	MILE Emissions Tests	V-3
V - 4	MILE Engine Emissions Test Results	V-4
V - 5	MILE and VTEL Comparative Aldehyde Test Results	V-6
V - 6	Aldehyde Emissions: City of Vancouver	V-8
V - 7	Aldehyde Emissions: Winnipeg Transit	V-9
V - 8	Aldehyde Emissions: Williams Moving & Storage	V-10
V - 9	Ranges of Methanol to Diesel Aldehyde Ratios	V-11
VI - 1	Methanol & Diesel Fuel Properties	VI-2
VI - 2	Methanol Malodourant Study Test Results	VI-4
VI - 3	Summary of Flame Luminosity Test Results	VI-6
VI - 4	Test Fuels Matrix	VI-9
VI - 5	BOCLE Test Results	VI-10
VII - 1	Incremental Capital Costs	VII-4
VII - 2	Bus Fuel Costs	VII-6
VII - 3	Truck Fuel Costs	VII-6
VII - 4	Incremental Annual Maintenance Costs	VII-9
VII - 5	Incremental Infrastructure Costs	VII-10
VII - 6	Summary of Annual Incremental Costs	VII-10
VII - 7	Fuel Price Sensitivity	VII-12
VII - 8	Crude Oil Price Sensitivity	VII-13
VII - 9	Emissions Profiles	VII-15
VII - 10	List of Emissions Factors	VII-16

CHAPTER I: INTRODUCTION

A. BACKGROUND TO PROJECT

Heavy trucks and buses are an integral component of the transportation system in Canada. This country depends heavily on its road network for distribution of goods and services, and most cities of any size operate public transit fleets. Municipal policies tend more to encouraging the use of buses in order to alleviate congestion problems caused by private cars. Nowadays almost all heavy trucks and buses in service are powered by diesel engines because this type of engine is far superior in fuel economy, reliability and longevity to a gasoline engine of comparable power and torque characteristics.

Supply and use of diesel oil and other petroleum derived fuels is nowadays no longer generally taken for granted, as it was 20 years ago. In fact it has become a subject of great social and political concern. Since 1970 the Canadian public has been forced into an awareness that petroleum fuels are:

- Extremely vulnerable to massive supply and price fluctuations caused by the volatile political situation in the Middle East.
- A finite resource which will become progressively more difficult to obtain in the future.
- Damaging to the environment and ecosystems at virtually all stages of their cycle of use, including extraction, refining, delivery and combustion in vehicle engines.

Possible alternative fuels, i.e., substitutes for petroleum fuels, have been under investigation for many years on a steadily growing scale. Their total history, as related to motor vehicles, extends back far beyond the "oil shocks" and "oil crises" of the 1970's. These events greatly increased public awareness of the work done in this field, and gave an impetus to further research and development which had not been experienced since the Second World War.

Alcohols have been recognized and used as fuels for vehicles since the dawn of motoring. In some respects, notably resistance to engine knock, they are a superior fuel to petroleum products. Spark ignition automobile type engines may be made to run on alcohol fuels with fairly simple modifications. However, diesel type engines do not adapt so readily, since the high auto-ignition temperatures and high enthalpies of evaporation of typical alcohol fuels, such as methanol and ethanol, are not compatible with the principles of compression ignition.

Consequently, many spark ignition engines have run on methanol and ethanol throughout motoring history, but it is only during the last 10 years that serious attempts have been made to produce a practical methanol or ethanol fuelled compression ignition engine. During this short span of development time a number of serviceable designs have emerged, and it is already well apparent that the overall principle of a methanol fuelled compression ignition engine is sound. However, there are many matters of detail to be resolved before this type could become a reliable general purpose prime mover to compete with, and possibly even supersede, today's diesel engines.

B. OBJECTIVES OF PROJECT

Energy, Mines and Resources Canada initiated Project MILE to define the feasibility of using methanol as an alternative fuel for heavy vehicles in Canada.

Methanol has a number of advantages to offer including the following:

- It may be produced in large quantities from readily available feedstocks including natural gas, coal, wood and biomass.
- It is a liquid fuel with freezing and boiling temperatures outside the range of Canadian climatic conditions.

- Production technology is very well established and large quantities are produced annually in Canadian plants.

At the time the project was planned, in 1983, the world market price for methanol was falling. Methanol is produced as a chemical feedstock in huge quantities on a global scale. Global production capacity had outpaced demand, and since 90% of Canadian methanol production is normally exported, the producing industry was experiencing a recession. If methanol could be proven as a motor vehicle fuel, then it would give the country a home produced alternative to petroleum, which could be made available in quantity merely by restoring the production rates of a depressed industry.

Whilst methanol prices were low, crude oil prices stood at historically high levels and were predicted to rise even higher. Introduction of a home produced vehicle fuel using abundant indigenous resources presented a very attractive prospect. By 1983 several world renowned engine manufacturers were testing heavy duty methanol engines, including the former Detroit Diesel Allison division of General Motors. Two-stroke diesel engines from this company have been widely used in Canadian urban transit buses for many years.

The sponsoring body, Energy, Mines & Resources Canada, called for Project MILE to put the methanol fuel, and the engines available, to work in Canadian transit and transport fleets. It was already proven that a bus could run using methanol fuel. The next question to be answered was whether a Canadian fleet could ever rationally contemplate converting to methanol as a practical new fuel in the near to medium-term future.

When the Project began the potential reductions in exhaust gas pollutants from methanol-fuelled engines were well recognized, but did not form the major reason for advancing the project. Since that time oil prices have not risen to the levels anticipated, having in fact fallen and remained at comparatively low levels, but the issue of vehicle exhaust pollution has grown in prominence. In particular new regulations governing exhaust emissions from diesel engines have been introduced in the U.S.A. and are expected to be introduced in Canada. The effect of this has been to reinforce the original emphasis of the project regarding substitution of petroleum based fuels with a need to reduce exhaust emissions from heavy vehicles.

C. SELECTION OF PARTICIPANTS

For the project to make a useful final statement regarding the feasibility of methanol as an alternative fuel for Canada, it was desirable to include a wide cross-section of vehicle types and fleet locations. There were some limitations placed on the freedom of choice in this respect, most notably the following:

- Project budget size
- Willingness of fleets to participate
- Choice of methanol engines available
- Geographical location of candidate fleets

It was decided that in order to achieve credible and statistically significant results test vehicles would be operated in pairs, and matched with a corresponding pair of control vehicles. Effectively this meant that to place one methanol vehicle in a test location really involved four vehicles. Only two were to be converted to methanol, but all four needed to be instrumented for data acquisition. Additional fleet related costs included fuel stations and training in safety and data gathering requirements.

The second point highlights a fundamental tenet of the whole project, namely that it should represent "real-world" operations.

All fleet participation in the project was voluntary. The vehicles were used in normal revenue earning operations and remained under the control and ownership of the fleets throughout the project. This was important to the total credibility of the project, particularly to the desired audience of fleet owners and operators. However, even if a fleet was willing to join the project it had to satisfy a number of conditions, including the following:

- It had to use one of the available engines.
- It had to be big enough to tolerate vehicle non-availability during conversion and potentially protracted repair time.
- It had to operate within range of a single fuelling facility.

The choice of engines was very restricted at the inception of the project. The heavy truck and bus engine market in Canada was essentially divided between five major manufacturers at that time: Cummins, Caterpillar, Detroit Diesel-Allison, Mack and International Harvester. Only Caterpillar and Detroit Diesel-Allison could provide methanol engines at a sufficiently advanced stage of development for use in the project. The Detroit Diesel engine has for many years been widely used in transit buses in Canada. The combination of this choice of engine, and the restriction on fuelling facilities made transit bus fleets a natural first choice for participation in the project.

Two city transit fleets, Medicine Hat, Alberta and Winnipeg, Manitoba agreed to run test buses for the project. Winnipeg Transit operated nearly 600 buses. Medicine Hat had 18 buses in its transit fleet. The city has a particular interest in methanol fuel, since Canada's largest methanol production plant is located there. The participation of these transit fleets in the project became more relevant as the project progressed. American regulations framed during the course of the project included separate lower emissions limits for urban buses, and led Detroit Diesel to commit its corporate efforts towards commercial production of a methanol engine by 1991.

Involving truck fleets in the project was more difficult because of the random nature of truck operations. Only specialist local delivery or fixed route vehicles can cope with a single fuel supply source. The Detroit Diesel methanol engine did not at that time develop sufficient horsepower for use in heavy highway trucks. The Caterpillar methanol engine, a larger displacement unit offering approximately 350 hp against the 250 hp of the Detroit Diesel unit, was more attractive to truck fleets.

Williams Moving & Storage Limited of Coquitlam B.C. agreed to install two Caterpillar methanol engines in new Kenworth tractor units due for delivery towards the end of 1987. These vehicles were replacement units in a fleet of trucks on contract hire to Sears Limited, used for a regular trailer exchange run between Coquitlam and a point on the B.C./Alberta border near Canmore. This was judged to be an excellent test of the methanol engines' potential, and helped to put a quintessentially Canadian face on the project derived from the Trans-Canada highway crossing of the Rocky Mountains.

The last of the four fleets participating in MILE joined in 1987. This was the City of Vancouver, which undertook to test two Cummins L10 model methanol engines in garbage collection trucks.

The entry of Cummins Engine Company into the project was most welcome because it broadened the scope of the trials by adding a new type of engine and a new type of fleet application. Furthermore, it involved an entirely different approach to the use of the new fuel. Expressed in simplistic terms the Cummins strategy was not to adapt the diesel engine to suit the methanol fuel, but to adapt the methanol fuel to suit the diesel engine. Imperial Chemical Industries (ICI), of the U.K., had developed a proprietary combustion enhancer additive called "Avocet". This additive was effective at 5% or less concentration levels, claimed to be safe in all normal handling and use situations, and produced a blended fuel which was similar in its physical properties to methanol until the point of injection into the engine cylinder, when it would ignite like diesel fuel. Therefore the Cummins engines required a minimum of mechanical modifications, no more than larger injectors and replacement of some fuel system seals and flexible pipes. Glow plugs or spark plugs were not necessary. The "L10" model engines offered to the project by Cummins used a 95% methanol, 5% "Avocet" fuel, and developed power and torque outputs equal to typical specifications for the original diesel version.

D. INVOLVEMENT OF NEW YORK STATE

Many other methanol engine test programs were getting under way at the same time as Project MILE, particularly in the U.S.A. They all shared the same overall objectives, to try to find an alternative to petroleum fuels, and to reduce harmful exhaust gas emissions. The New York State Energy Research and Development Authority (NYSERDA) contacted Energy Mines and Resources regarding joint participation in MILE, and in 1986 an agreement was signed providing for NYSERDA to contribute funding to establish test fleets in New York State. Two locations were selected, the City of Buffalo, where two methanol transit buses were to be placed in service for the Metro Transit fleet, and Kennedy International Airport. The airport operation was to convert two inter-terminal shuttle buses to methanol fuel. These buses were owned and operated by Hudson General Corporation, which provided the ground services at Kennedy Airport and many other airports in the U.S.A. and Canada.

The NYSERDA buses were all to operate on methanol/Avocet, and this part of the project was to explore the possibilities of simple conversions of existing engines. NYSERDA was particularly interested in the question of quickly turning over large numbers of current vehicles to alternative fuels, and the additive ignition enhancement approach was an obvious strategy. All four buses used Detroit Diesel two-stroke engines, some of which had already accumulated over 160,000 km of service on normal diesel fuel. The conversion work for methanol was to be carried out either in the fleet workshop or by a local DDC dealer, and involved fitting larger capacity injectors, an electric fuel pump, and changing fuel lines and seals to methanol compatible materials.

This segment of the project did not expand as rapidly as intended. In particular many problems were encountered in designing and building fuelling facilities to conform to the stringent New York State regulations. A brief period of operation demonstrated the feasibility of the idea, and this was augmented by a program of emissions tests on one of the converted engines.

E. OVERALL STATUS

Project MILE included new engines provided by three of the major suppliers to the Canadian heavy-duty truck and bus market, Caterpillar Incorporated, Cummins Engine Company, and Detroit Diesel Corporation. (Detroit Diesel Allison Division of General Motors until January 1988). Project vehicles used pure 100% and additive enhanced methanol fuel. It also addressed the on-site conversion of existing diesel engines to methanol fuelling. This spread of sources and technologies encompassed most of the current prospects for methanol power in buses and trucks. During the time of the project there were many detailed developments made in the technology of heavy-duty methanol engines, often with far-reaching results, but few really fundamental changes in design emerged until 1989 when ultra-high compression ratios introduced the possibility of using 100% methanol fuel without glow plugs or spark plugs.

The project therefore remained topical throughout its duration and provided some of the most relevant and realistic methanol operating experience accumulated in the world of bus and truck operations.

CHAPTER II: OBJECTIVES

The overall objective of Project MILE was to demonstrate the viability of methanol as an alternative fuel for Canadian truck and bus fleets, accounting for all aspects of fleet operation including technical, economic and social factors.

The project was intended to provide Energy, Mines and Resources Canada with a clear understanding of how, where, when, and at what cost or benefit methanol could be used as an alternative fuel in the Canadian medium and heavy-duty road transportation sector.

In order to achieve the overall objective it was determined that the MILE vehicle test program had to meet the following criteria:

- Apply methanol fuel in typical vehicle applications where diesel is normally used.
- Include a variety of fleet types, vehicle types and vehicle applications.
- Operate test vehicles nationwide to account for different geographical and climatic conditions.
- Have the test vehicles perform actual revenue generating work in normal fleet operating conditions.
- Examine all facets of methanol fuel use including fuel distribution and handling, vehicle systems, vehicle performance and life-cycle costs.
- Include a timely and comprehensive information and technology transfer process.
- Consider potential social questions associated with the introduction of methanol fuel.
- Examine and document the overall economic feasibility of methanol fuel use.
- Make maximum use of Canadian resources and expertise in order to expand national knowledge of alternative fuels, and enhance Canada's international standing in this field.

CHAPTER III: TECHNICAL

A. FLEET VEHICLES

A.1. Fleet Composition

The MILE Program evaluated three different types of methanol engines in four fleets. The fleets, located across Western Canada, represented a broad spectrum of heavy duty engine applications, from transit buses to class 8 tractor trailers. The widely spread geography of the fleet locations permitted insight into engine operation in different climates and the logistics of fuel supply to various locations.

An identical number of diesel powered control vehicles was used at all sites to permit a direct comparison between methanol and diesel. The diesel control units were subjected to the same data recording and logging procedures.

The diesel control vehicles provided by the City of Vancouver and Williams Moving and Storage were duplicates of the vehicles converted to methanol power. Engine power and torque outputs were matched to allow valid comparisons of fuel consumption and performance characteristics.

At Winnipeg and Medicine Hat the control vehicles were identical apart from using the 71 series DDC engine, model 6V-71N. This was a smaller displacement (6.9 litres), naturally aspirated engine, using the conventional Detroit Diesel mechanical injector control and governor system. Both bus fleets specified the 200 bhp rating version. To maintain as close comparability as possible in the circumstances the methanol 6V92TA engines were also set to 200 bhp at 2100 rpm.

Tables III-1 and III-2 summarize vehicle and engine data for the methanol vehicles.

Figures III-1, III-2 and III-3 illustrate typical project vehicles.

A.2 Engines - Detroit Diesel

The Detroit Diesel methanol engines were conversions of the 6V-92 series diesel engine. This was the latest derivative of a 2-stroke design used in 90% of the buses in Canada and the USA. The basic diesel unit was available in the 6V-92TA form (turbocharged, aftercooled), in 253 bhp and 277 bhp ratings. The methanol engines used the Detroit Diesel Electronic Control (DDEC) system introduced in 1985. The methanol engines originally supplied to MILE incorporated the following modifications.

(1) Glow plugs:

Glow plugs were fitted to the engine to provide additional heat to the combustion chamber prior to start up and during engine operation at idle and low loads. An engine mounted control box distributed power to all six glow plugs and turned the plugs on or off according to engine temperature. The DDEC unit provided an input signalling when the glow plugs were to be switched on and off.

(2) Blower Bypass Control:

A blower bypass control on the methanol engines limited the amount of cold scavenge air at idle and low loads, thus avoiding possible flame quenching. Based on the engine operating point, an electronic signal was fed to an electro-pneumatic controller (blower by-pass control actuator) which opened or closed the bypass valve to regulate the amount of scavenge air.

(3) Engine Compression Ratio:

The compression ratio was raised from 17:1 to 19:1 to provide higher compression heating effect.

Fleet	Vehicle Make	Vehicle Type	Fleet Nos.	Year	Engine	Application
Winnipeg Transit	Flyer D901	40ft. Urban Transit Bus	601 602	1986 1986	DDC 6V-92TA	Urban passenger transit
Medicine Hat Transit	GMC "New Look"	40 ft. Urban Transit Bus	754 759	1978 1979	DDC 6V-92TA	Urban passenger transit
City of Vancouver	Freightliner	COE 3-axle truck	B1874 B1875	1988 1988	Cummins L10TA	Industrial garbage packer
Williams Moving & Storage	Kenworth W900	Tandem axle tractor unit	I272 I289	1987 1987	Caterpillar 3406DITA	Long distance haulage.
Hudson General	T.M.C.	40ft. Transit Bus		1985	DDC 8V-71N	Airport terminal shuttle.

Table III-1. Project MILE Vehicles

Make	Type	Configuration	Displacement	Power	Fuel	Compression Ratio	Combustion Technology
Detroit Diesel Corp	6V-92TA	V-6 two-stroke Turbocharged Aftercooled	9.1 litres 552 cu. in.	200 bhp @ 2100 rpm (Initial) 253 bhp @ 2100 rpm (Winnipeg) 277 bhp @ 2100 rpm (Medicine Hat)	100% Methanol	19:1 Later Versions 23:1	Scavenge Air Control Glow Plugs (See text) Electronic Control
Cummins Engine Co.	L10-TA	L-6 Turbocharged Aftercooled	10.0 litres 610 cu. in.	240 bhp @ 2100 rpm and 270 bhp @ 2100 rpm	95% Methanol 5% "Avocet"	18:1	Ignition enhancer additive.
Caterpillar Inc.	3406 DITA	L-6 Turbocharged Aftercooled	14.6 litres 890 cu. in.	350 bhp @ 2100 rpm	100% Methanol	16.1	Glow plugs

Table III-2. Project MILE Engines

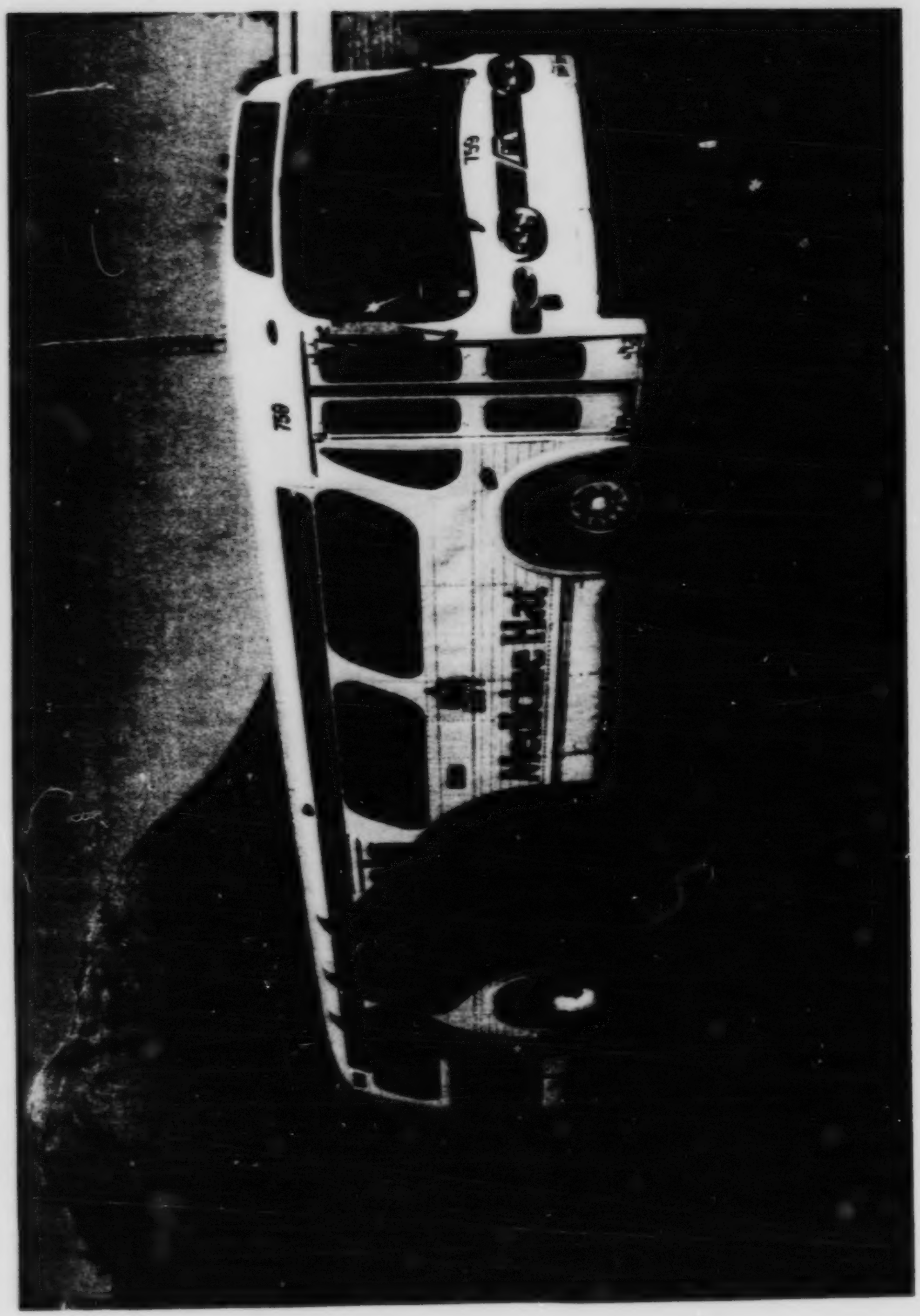
759
Medicine Hat

Figure III-1. GMC Methanol Bus - Medicine Hat

Figure III-2. Flyer Methanol Bus - Winnipeg

Figure III-3. Kenworth Methanol Truck - Williams

(4) Injector tip size:

Injector tip size was increased to accommodate the larger volume of fuel required at each stroke.

During the course of the MILE program. DDC made significant improvements to the methanol engines, based on laboratory work and in-field experience gained from various demonstration programs, including MILE. A new electronic control system (DDEC II), a more rugged blower by-pass actuator, new exhaust camshaft profile and inlet port timing were introduced in fall 1988. Changes to fuel injectors enabled differences between engine power ratings to be handled by the programmable parameters of the DDEC system, and provided significant reductions in emissions. The use of DDEC II also simplified the amount of electronic hardware required compared to DDEC I. The electronic control module (ECM), blower bypass control and electronic distributor unit of DDEC I were combined into a single engine mounted component with DDEC II.

Glow plugs were originally controlled on a simple on/off basis. This was changed to incorporate modulation of heat output during the on phase. The objective remained to reduce glow plug use to an absolute minimum. A later version of the engine, introduced into the project just after the period covered by this report, required glowplugs only for cold starts and warm up.

The glow plugs went through a number of detail design changes, all concerned with improving the mechanical reliability of the external electrical connection. The location of the plugs deep down inside the head casting demanded some type of extension link to connect to the wiring harness, and these extensions tended to be vulnerable to vibration damage. This was a good example of the type of detail problem which absorbed a disproportionate amount of time to solve.

Upgrading of Project MILE DDC methanol engines to the new specifications began in August 1988, starting with Winnipeg Transit. Medicine Hat's engines were completed in October 1988. At the request of the Medicine Hat fleet engine power output was increased to 277 bhp @ 2100 rpm. In May 1989 the two Winnipeg engines were re-rated to 253 bhp @ 2100 rpm.

Figure III-4 shows a pre-production version of the DDC 6V-92TA methanol engine.

A.3. Engines - Caterpillar

The Caterpillar methanol engine was directly based on the diesel 3406 DITA engine. (Direct Injection, Turbocharged, Aftercooled). This is a popular engine for class 8 trucks and heavy equipment. It is of straightforward basic design, using a separate Caterpillar injection pump and fuel nozzles, four valve heads and various turbocharger/aftercooler combinations to provide power outputs in the 300 bhp to 425 bhp range. The project methanol engines were set for 350 bhp @ 2100 rpm, and were fitted with the patented "Brakesaver" hydraulic retarding unit. Figure III-5 illustrates one of the Caterpillar methanol engines used in the project.

The methanol version of the Caterpillar 3406 engine supplied to MILE was identical to its diesel counterpart with the following exceptions:

(1) Glow Plugs:

Modulated glow plugs were used as an ignition source, powered by an auxiliary engine driven alternator. Power supplied to the glow plugs was inversely proportional to the engine load; as engine load increased, combustion chamber temperatures rose and less external heat input was required. The glow plugs were controlled through a glow plug alternator control (GPAC) and power distribution box, both located inside the vehicle cab.

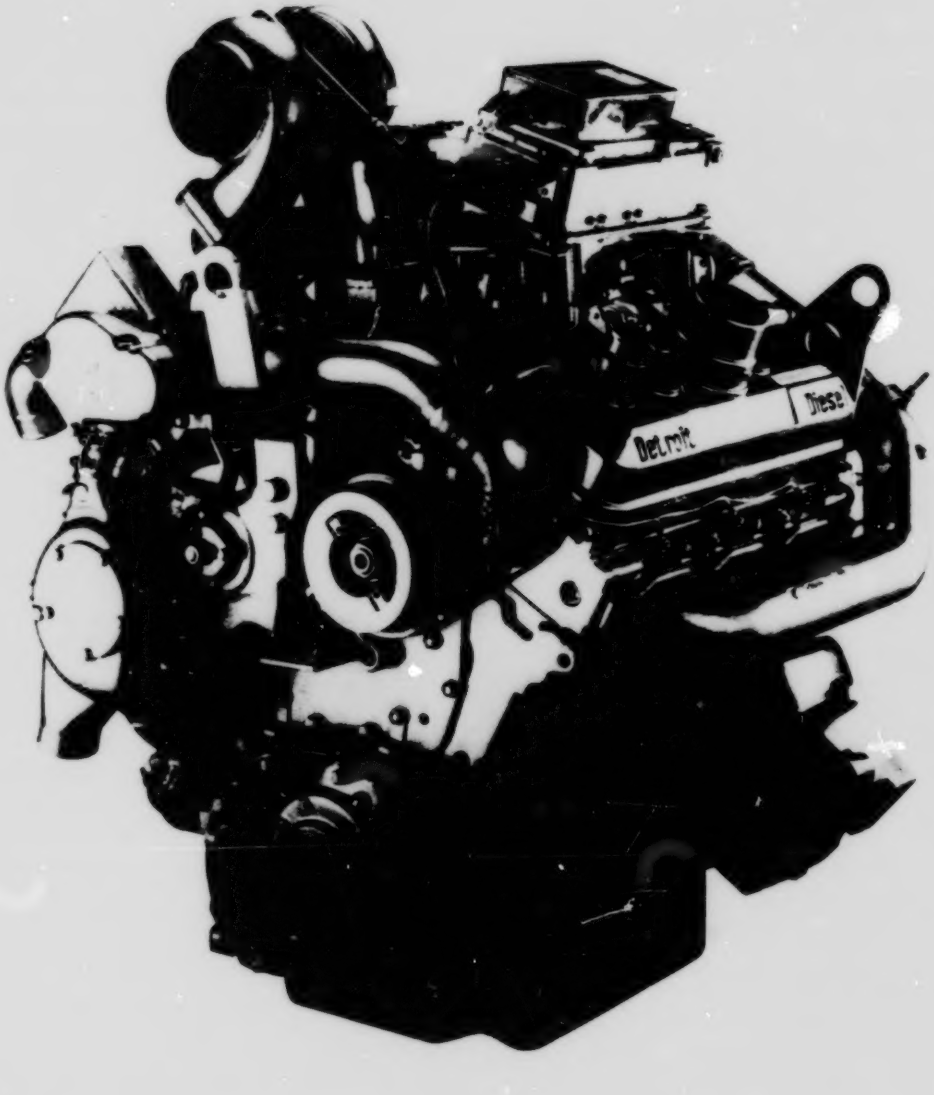
Detroit
Diesel

Figure III-4. Detroit Diesel 6V-92TA Methanol Engine

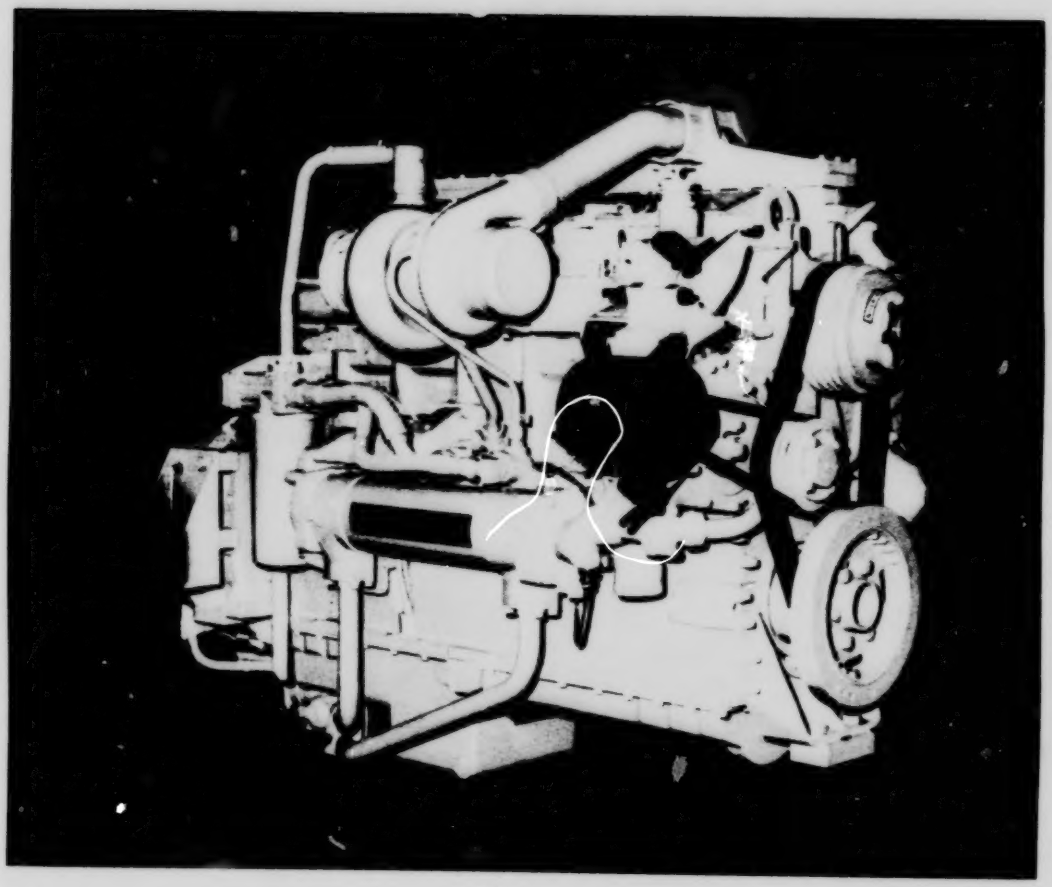

Figure III-5. Caterpillar 3406 DITA Methanol Engine

(2) Pistons:

Piston crowns were modified to incorporate a central steel impingement pin. The pin aided in breaking up the fuel spray and ensuring atomization, as well as relieving the piston crown of some thermal shock effects due to the high cooling effect of methanol injection.

(3) Fuel Injection System:

The fuel pump and injector capacity was increased to account for the lower volumetric energy content of methanol relative to diesel fuel. To minimize injector fouling from lubricating oil pyrolisation an externally mounted reservoir of lubricant, pressurized off the truck air supply, was used to lubricate the fuel pump. Lubricant was sprayed against the lower half of the injector plunger. Fuel pump lubricant conformed to MIL L-23699C (specification for lubricating oil, aircraft turbine engine, synthetic base).

The Caterpillar engines operated on a mixture of methanol and "Maxlube 8027," a corrosion inhibitor, in the ratio of 0.025% (V/V) Maxlube in methanol. All methanol-Maxlube blending was performed external to the vehicle fuel system.

A.4 Engines - Cummins

The Cummins methanol power unit was a version of the L10 diesel, a mid-range unit available in ratings from 200 bhp to 300 bhp. The methanol engines supplied to the project were turbocharged and aftercooled. A typical example is shown in Figure III-6.

Unlike the approach of Caterpillar and DDC who modified their diesel engines to burn methanol, the approach of Cummins was to modify the fuel to burn in its engine. The methanol used contained 5% (V/V) "Avocet", a cetane enhancer produced by ICI Chemicals. Because of this approach a minimum of mechanical modifications were required, and outwardly, both the methanol and diesel engines were quite similar in appearance. The methanol engines featured an increased compression ratio (18:1) to aid fuel ignition, an increased capacity fuel pump and injectors, along with timing changes to optimize combustion. Two versions of the methanol L-10 engine were used in the MILE program. The first methanol engine and both diesel control engines were rated at 270 bhp at 2100 rpm. The second methanol engine, delivered in winter 1989, was rated at 240 bhp at 2100 rpm. The second engine featured changes to fuel pump calibration, a different cam profile and fuel injectors with the same spray pattern as used in the diesel engines. These changes were aimed at reducing regulated exhaust emissions and improving engine durability. The 240 bhp power rating was intended primarily for use in transit buses.

A.5 Transmissions and Engine Auxiliaries

All project vehicles retained the transmissions, drivelines and axles originally fitted for the standard diesel engines. Both transit bus fleets and the city of Vancouver garbage trucks used Allison automatic transmissions. Medicine Hat buses were fitted with the 3 speed V-730 "vee-drive" transmission which is widely used in combination with Detroit Diesel bus engines. The newer Winnipeg buses had the V-731 model, an updated, electronically controlled, version of the V-730. The garbage trucks employed the HT 745 transmission. The Williams Caterpillar trucks used 15 speed Fuller transmissions with tandem Eaton rear axles, ratio 3.70:1. No changes were made to transmission or axle ratios, or to shifting schedules in the case of the automatics.

The only transmission modifications made during the project were to the V-731 Allison transmissions at Winnipeg. The direct drive disengagement speed was too low for the higher idling speed of the methanol engines, and tended to stall the engine during sudden stops. Some difficulty was experienced in matching the methanol electronic engine control system to the

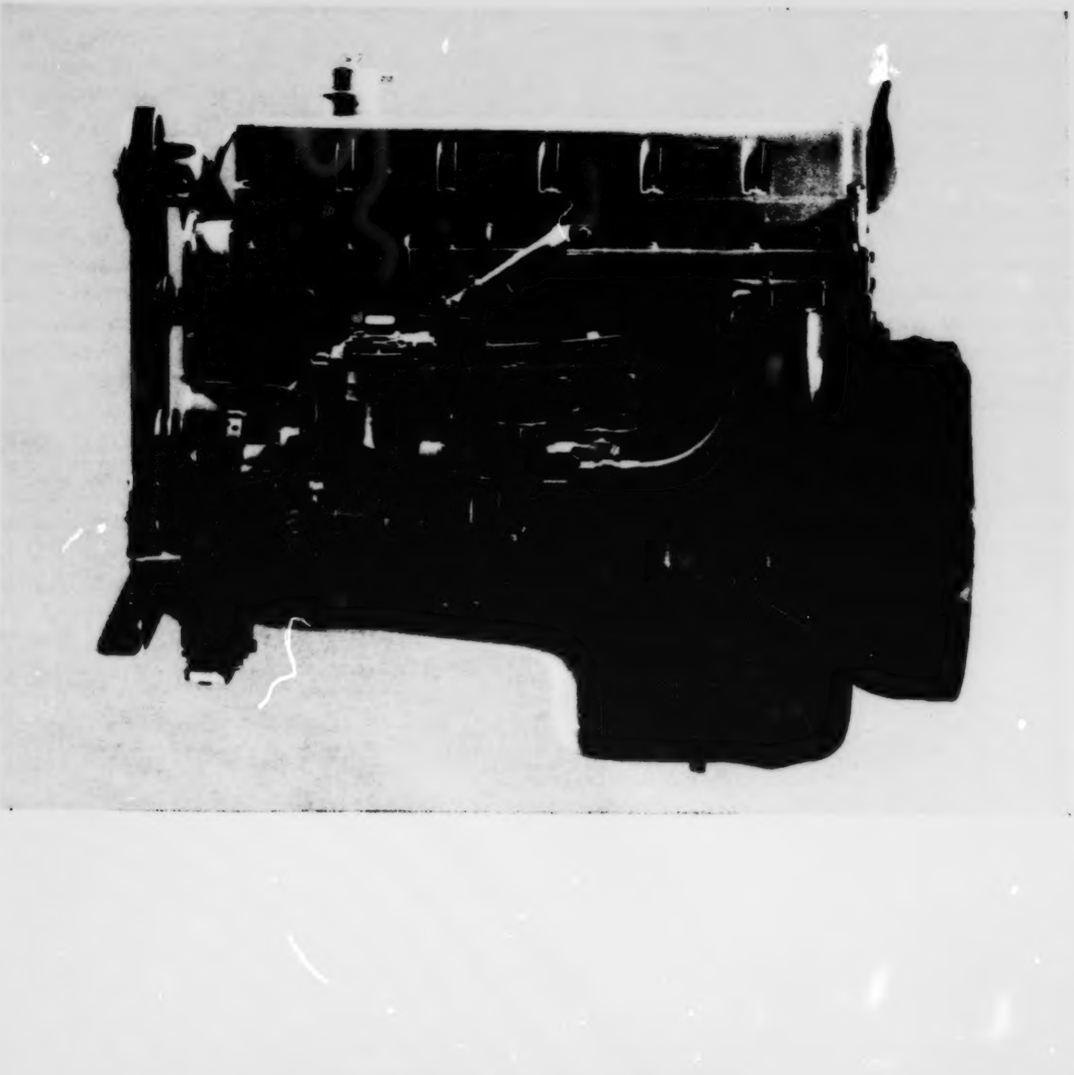

Figure III-6. Cummins L10TA Methanol Engine

corresponding transmission controls to achieve satisfactory part load shifts, but this was eventually overcome when the second generation engine system (DDEC II) came into use. The engine stalling problem was solved by an appropriate resetting of the transmission disengagement speed.

No changes were made to the original diesel specification radiators, cooling fans or thermostats on any project vehicles, and cooling system capacities and operating pressures were the same for the methanol and diesel engines.

Engine oil sump capacities, oil circulation rates and pressures were likewise unchanged. The DDC engines required special low ash oils, supplied by three different manufacturers during the project. The Cummins engines operated on the regular 15W-40 specification oil used in the Vancouver fleet, and the Caterpillar engines used a combination of 30 or 40 grade diesel oil in the crankcase with a separate total loss synthetic oil feed to the fuel injection pump plungers.

The extensive modifications necessary to the inlet air and exhaust systems on the project buses were not required for either of the truck fleets. Both Caterpillar and Cummins methanol engines used the original diesel air filters, inlet and exhaust manifolds and mufflers.

B. VEHICLE CONVERSION

B.1 Winnipeg Transit - Flyer/DDC Buses

Conversion work on the Winnipeg Transit Flyer buses took place at Midwest Detroit Diesel, the local DDC dealer. Flyer Industries is located in Winnipeg and was able to provide engineering support and spare parts.

Engine Installation

The conversion of the buses involved removal of the series 71 naturally aspirated engine and replacement with the series 92 turbocharged engine. Figure III-7 illustrates the original diesel engine installation. The new engine utilized the DDEC system which necessitated extensive electrical rewiring between the engine, transmission and driver's compartment. All auxiliary engine mounted components, such as the air compressor, power steering pump and alternator were transferred from the diesel to the methanol engine at this time.

The use of a turbocharged engine necessitated a complete replumbing of the air and exhaust system. A new air cleaner and muffler were used to accommodate the increased gas flow.

The relatively large engine compartment of the Flyer bus proved to be advantageous. It was possible to maintain the location of the air cleaner and muffler, and customize new duct work to handle exhaust gas to and from the turbocharger. No external modifications to the rear of the vehicle body were required to accommodate the methanol engine.

Figure III-8 shows the final methanol engine installation. The extra space occupied by the turbocharger and exhaust is apparent when compared to Figure III-7. Also shown is the glow plug control box and fuel cooled electronic distributor unit (below and to left of turbocharger), the auxiliary alternator (left of rear cylinder head) and the blower by-pass valve actuator. (immediately above right hand end rear cylinder head)

Fuel System Upgrade

The bus was originally supplied with one 545 litre terne plated steel tank. This was replaced with two 545 litre fuel tanks, made from 11 gauge stainless steel fabricated to the identical dimensions of the original fuel tank with similar baffle plate arrangements. Two fuel tanks were required to meet Winnipeg Transit's desired daily operating range of at least 12 hours of uninterrupted service. Because of space constraints on the vehicle underside, two interconnected tanks were easier to fasten

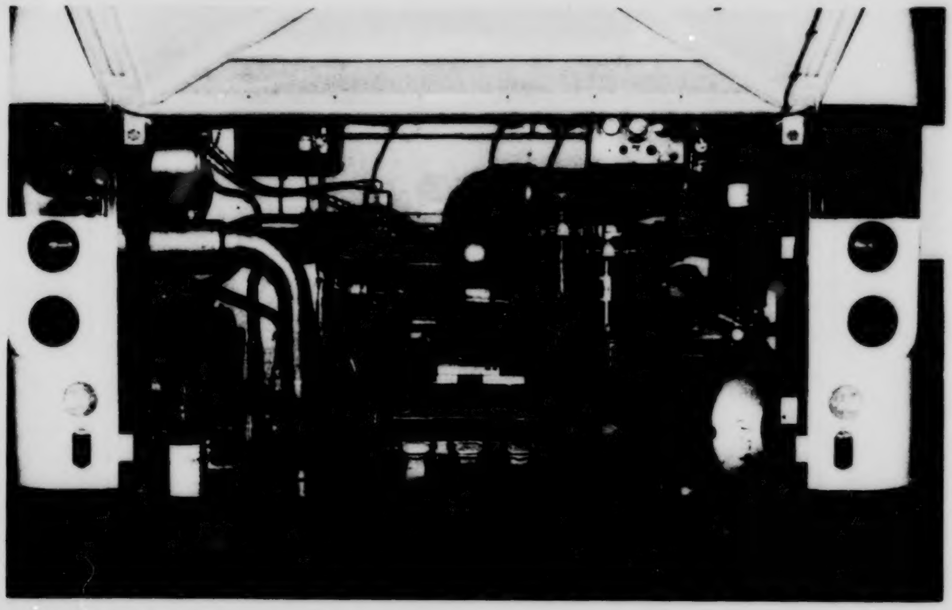

Figure III-7. Detroit Diesel 6V-71N Diesel Installation (Flyer)

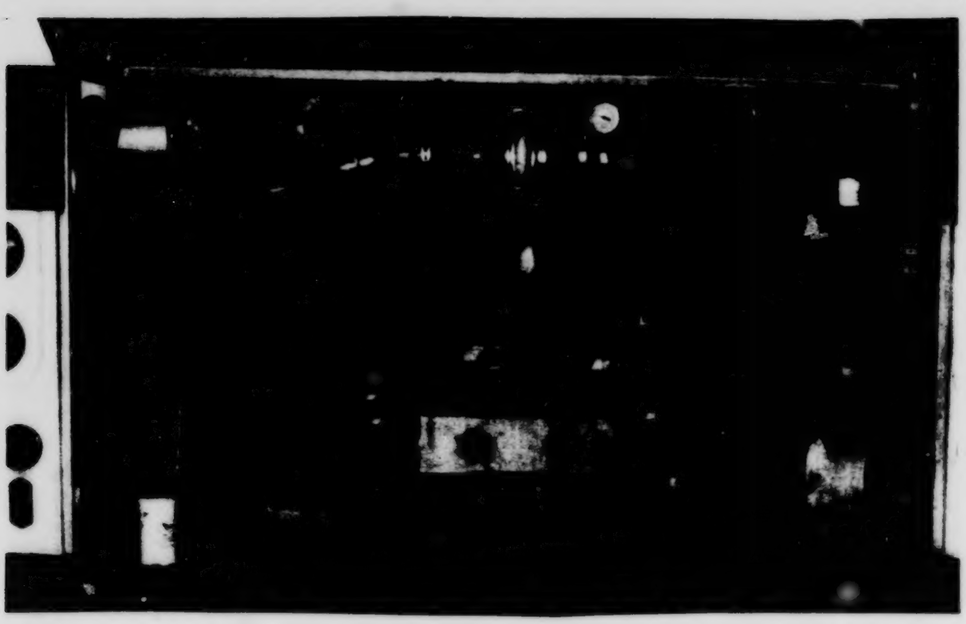

Figure III-8. Detroit Diesel 6V-92TA Methanol Installation (Flyer)

to the chassis than one 1000 litre fuel tank. This decision was made in consultation with Flyer Industries.

To accommodate the second fuel tank, an additional set of main rails, running parallel to the vehicle center-line, were installed under the floor boards. A new bulkhead was also installed, just forward of the existing fuel tank, to create a cavity for the second fuel tank. The fender skirts around the second fuel tank were strengthened with a rail and struts to protect the tank in the event of a sideways impact. All major components used to mount the additional fuel tank were standard Flyer components purchased through the factory.

The fuel tanks were interconnected by three flexible pipes to allow for normal vehicle flexing. Both tanks were filled through a sealed type "dry-break" connection (Emco Wheaton) illustrated in Figure III-9. The fuel filler neck was extended to within 2.5 cm of the tank bottom to minimize splash and hence any static charge buildup during refuelling. Both fuel tanks were fitted with Emco Wheaton level control and pressure relief valves to permit tank venting during fill-ups and to relieve excess pressure. Figure III-10 illustrates the EMCO Wheaton fuelling equipment as used on all project vehicle fuel tanks. Many of the system components were made of aluminium alloy, which caused subsequent corrosion and operational problems. Attempts to nickel plate in-tank parts such as the level control valve were only partly successful in preventing corrosion. Late in the project EMCO supplied new equipment with an anodized finish to resist methanol.

The DDC engines required an external electric fuel pump and cooler unit to provide fuel pressure for starting, and to prevent fuel boiling in the engine galleries or at the fuel pressure restrictor orifice. The pump, cooler and primary and secondary filters were all mounted behind the left hand front wheel of the bus. The cooler was provided with twin electric fans which operated continuously while the engine was running. (Figure III-11) A fuel system pressure switch was provided to turn off the pump in event of major fuel leaks.

Electrical System

Extensive electrical system modifications were required. The DDEC system consisted of an electronic control module (ECM), electronic distributor unit (EDU), electronic foot pedal assembly (EFPA) and, unique to the methanol engine, a blower by pass control unit and glow plug controller. The ECM and blower bypass unit were installed alongside the existing Allison transmission electronic control (ATEC) box in the rear left hand side electrical storage compartment. Figure III-12 shows the ATEC box in place. The ECM and by-pass control unit were similar dimensionally and installed on top of each other to the left of the ATEC box. The EDU unit was responsible for injector solenoid control and dissipated large amounts of heat. It was mounted on top of the engine to permit cooling by circulation of incoming fuel through a copper coil built into the cover plate. The glow plug control and monitoring box was bolted on top of it. (See figure III-8).

A transmission engine communications link (TECL) permitted the DDEC and ATEC systems to communicate. The standard DDEC wiring harness was customized at the site to accommodate the methanol and ATEC features of the vehicle.

Two new electrical circuits were provided, one to power the fuel pump and cooler fans, the second for the glow plugs. Each circuit had a separate switch so that it could be isolated for testing. Figure III-13 is a schematic of the extra circuits. Because of the increased electrical demand due to the glow plugs, fuel pump motor and cooler fans, an auxiliary alternator was installed to ensure that the batteries would remain charged. (Figure III-8) The standard battery pack, rated at 1200 amp-hrs, was retained.

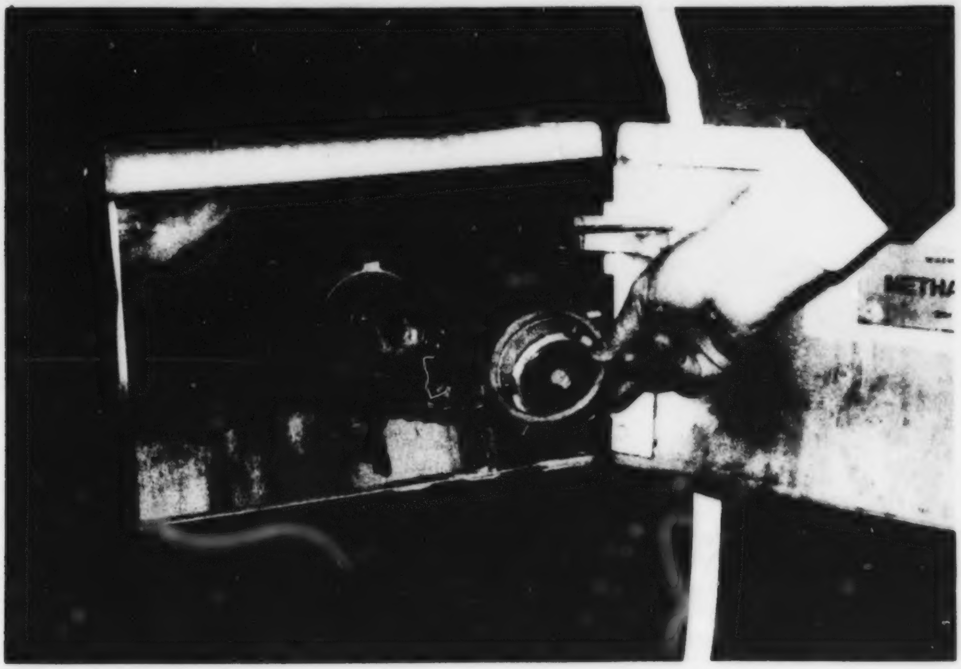

Figure III-9. Positive Locking "Dry-Break" Fuelling Connector

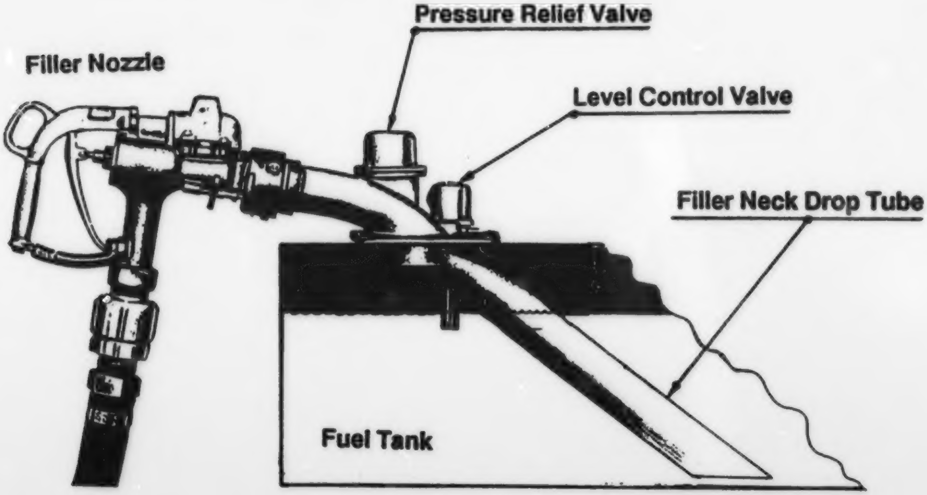
Pressure Relief Valve
Filler Nozzle
Level Control Valve
Filler Neck Drop Tube
Fuel Tank

Figure III-10. Emco-Weaton "Dry-Break" Fuelling System

Figure III-11. Methanol Bus Fuel Cooler Unit

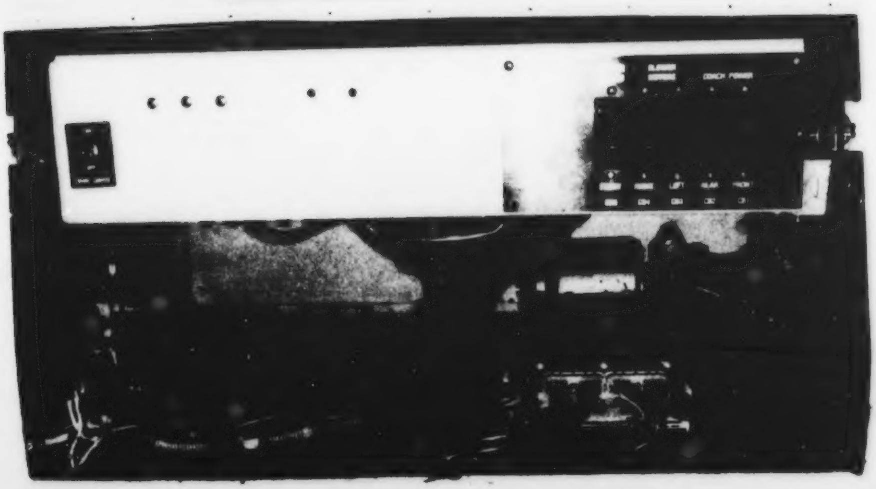
COACH POWER
LEFT
REAR
FRONT

Figure III-12. Electronic Control Box Location (Flyer

Engine Operations

The glow plugs were automatically energized by turning the ignition switch to the "run" position. A timing light warned the driver to allow the glow plugs to operate for 60 seconds before pressing the starter button. Pre-heat warning time was manually adjustable through a timer located in the electrical compartment. The electric fuel pump and fuel cooler fans were also energized by the ignition switch and remained on continuously during engine operation.

Figure III-14 shows the extra dashboard instrumentation, consisting of five lights to indicate glow plug preheat time, fuel temperature, fuel pressure, check engine and stop engine. The check engine light and stop engine light were part of the standard DDEC instrumentation package.

glow plug light - Indicated the recommended pre-heat time. (60 seconds)

fuel temperature - Indicated if the temperature on the exit side of the fuel cooler exceeded 66^{O}C, warning the driver that fuel temperature exceeded boiling point.

fuel pressure - Warned the driver when fuel pressure dropped below 40 psi. The switch was designed to shut the fuel pump down in the event of a major fuel leak to minimize the quantity of fuel spilled. A timer circuit delayed switch operation when starting to allow the system to prime itself.

check engine - Indicated that the DDEC system had detected a system fault during engine operation. A DDEC system diagnostic reader tool was used to reveal the detected fault through an error code.

stop engine - As above, but for cases where the engine fault was severe enough to require engine shutdown.

B.2 Medicine Hat Transit - GMC Buses

The two Medicine Hat Transit coaches were also converted to methanol power at Midwest Detroit Diesel in Winnipeg. The overall conversion procedure was similar, as both Winnipeg and Medicine Hat buses were repowered with identical methanol engines, but the different vehicle chassis necessitated many detail changes.

Engine Installation

The GM coach engine compartment presented a much more confined envelope in which to mount the 92 series methanol engine. There was some initial concern that the methanol engine would not fit into the vehicle because the "Newlook" coach uses different engine cradles for the 6V-71 and the 6V-92 engines. The major difficulty was accommodating the inlet air and exhaust plumbing, plus the EDU and glow plug controller, into the engine compartment. Because of lack of space, the air cleaner was fitted within a specially built stainless steel box on the parcel deck behind the rear seat of the bus. (Figure III-15)

The muffler was left in its standard location just forward of the engine, below the fire wall. The center section of the engine access door had to be extended outwards to accommodate the engine mounted EDU and glow plug control boxes, which protrude above the rear-engine rocker cover. (Figure III-16)

Fuel System

The Medicine Hat methanol bus fuel system was identical to the one used on the Winnipeg methanol buses, except only one fuel tank per vehicle was used. The existing fuel tank of nominal 450 litre capacity was replaced with one of 545 litre capacity. To accommodate the larger capacity fuel tank, the fuel tank support saddles were lengthened and collars were used to stiffen the mounting bolts. The standard fuel tank mounting location was retained. The electric fuel pump, cooler, fans and fuel filters, were mounted underneath the centre of the bus.

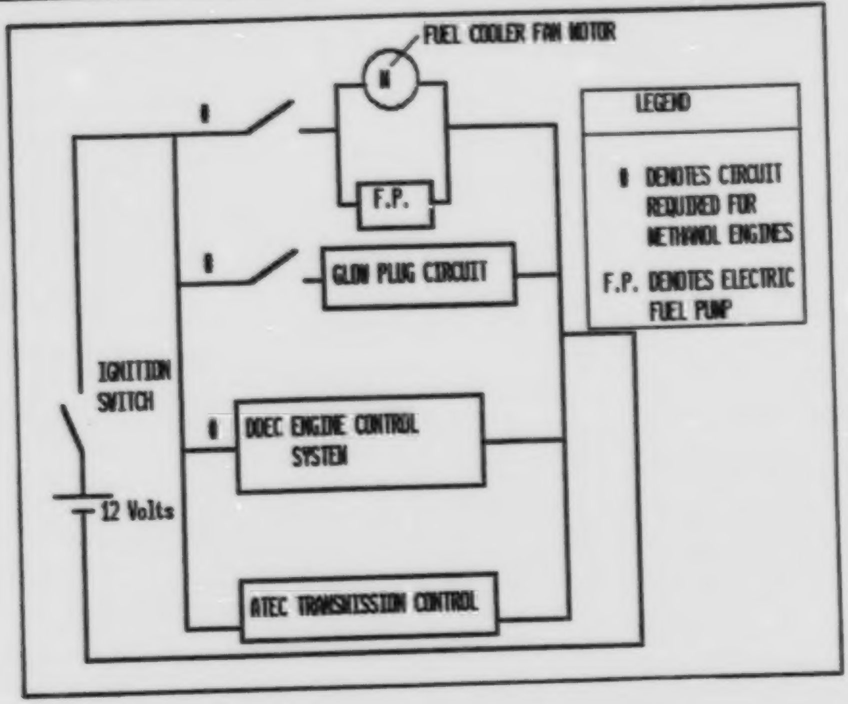
FUEL COOLER FAN MOTOR
M
F.P.
GLOW PLUG CIRCUIT
DDEC ENGINE CONTROL SYSTEM
ATEC TRANSMISSION CONTROL
IGNITION SWITCH
12 Volts
LEGEND
# DENOTES CIRCUIT REQUIRED FOR METHANOL ENGINES
F.P. DENOTES ELECTRIC FUEL PUMP

Figure III-13. Methanol Bus Electrical System Schematic

30
0
150
STOP
REQUESTED
VENT

Figure III-14. Methanol Bus Dash Panel Warning Lights

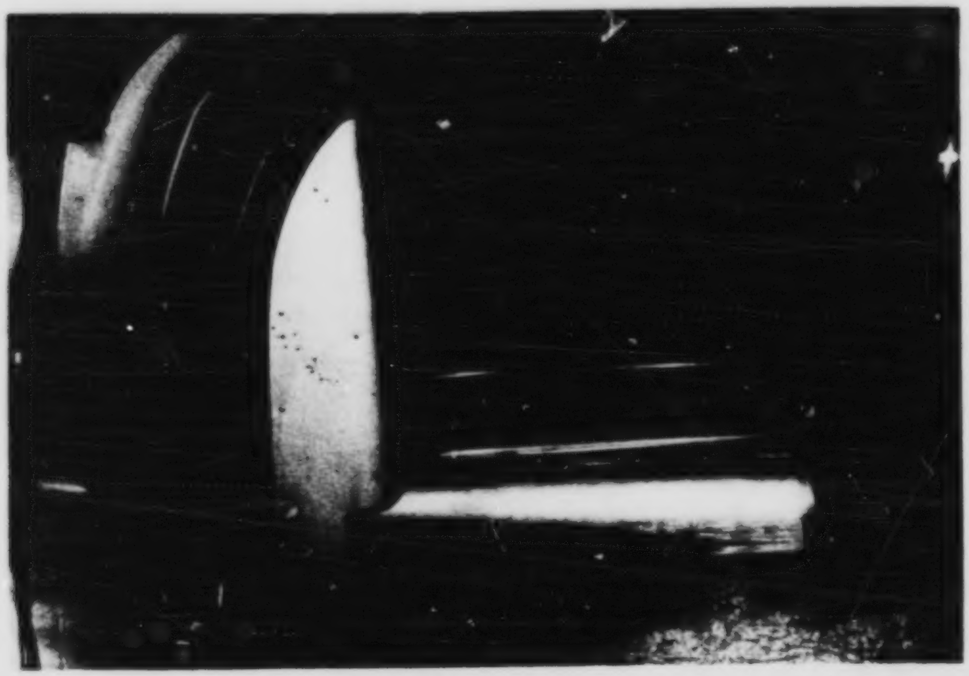

Figure III-15. Fabricated Air Filter and Intake Cover (GMC)

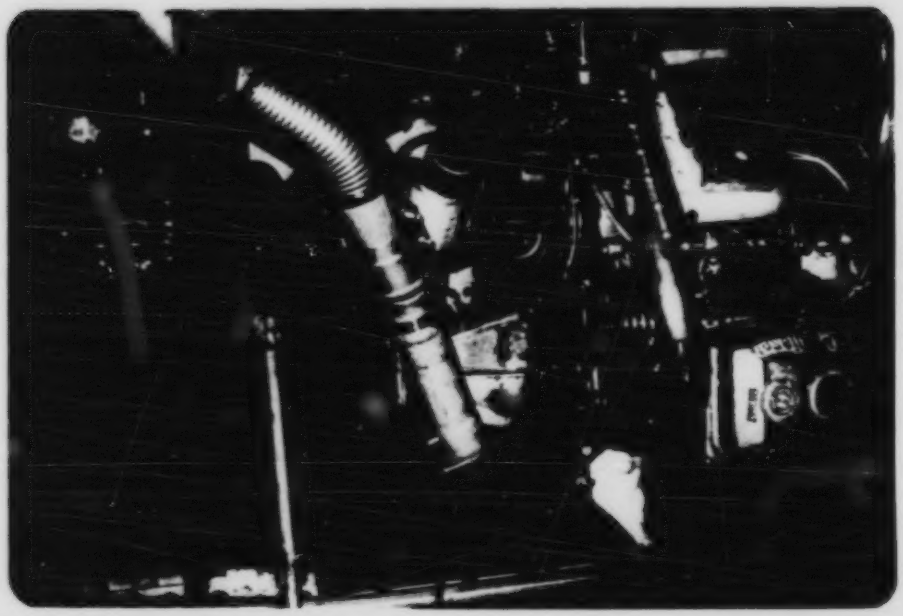

Figure III-16. Glow Plug Control Box and Fuel Cooled Electronic Distributor Unit

Figure III-17. Fuel Filters and Electric Fuel Pump

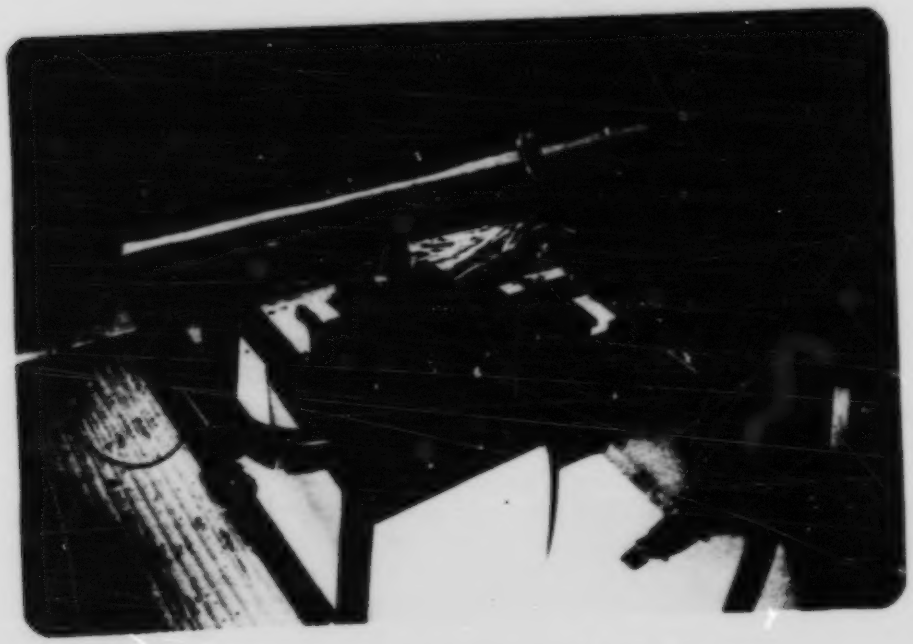

Figure III-18. DDEC Control Boxes Location (GMC)

Figure III-17 shows the primary and secondary fuel filters mounted underneath the bus. The electric fuel pump is immediately behind the tops of the filters. The cooler used was the same as the unit fitted to the Flyer buses as shown in Figure III-11.

Electrical System

Electrical modifications to the GM coaches were the same as for the Flyer coaches with one exception. Since the buses were equipped with the Allison V-730 transmission the standard pneumatic throttle had to be retained. A rheostat was added to provide an electronic throttle position signal for the DDEC. The pneumatic signal was routed into the transmission control module in the normal way. Because of the general lack of space in the GMC bus the electronic control module (ECM) and blower by-pass control boxes were fitted under one of the rear bus seats. (Figure III-18). The boxes were enclosed by a sheet metal case to prevent damage or interference.

B.3 Williams Moving And Storage

The involvement of Williams Moving and Storage in MILE presented a unique opportunity to build methanol vehicles on a production line. At time of entry into the MILE program, Williams had on order two new Kenworth model W900 trucks. Williams, Kenworth and Caterpillar agreed to install methanol engines in these trucks at the Kenworth plant in Ste. Therese, Quebec.

The conversion procedure was eventually carried out in three distinct phases. Phase I involved building the trucks with methanol engines at the Kenworth factory. Phase II was performed at the British Columbia Caterpillar Dealer, Finning Inc., where the fuel system and engine controls unique to the methanol engine were installed. Phase III consisted of the vehicle predelivery checkout at Inland Kenworth, the Kenworth dealer through which the vehicles were purchased.

Figure III-19 shows the first of the two methanol trucks with a typical load of double van trailers.

The installation of the methanol 3406B engine into a W900 chassis necessitated some minor changes to the standard build, including relocation of the power steering pump and reservoir. Other minor components (hoses, coolant filter-conditioner, etc.) also had to be relocated in order to accommodate the second alternator used to power the glow plugs. (Figure III-20 and III-21) All these changes were easily carried out either on the assembly line or at the vehicle checkout area located at the end of the assembly line. However, it was not possible to run the engines since Kenworth would not permit methanol fuel inside the factory because of the fire risk.

No fuel tanks or lines were fitted during assembly. Methanol fuel tanks were fabricated from stainless steel by an outside contractor based on engineering drawings provided by Kenworth. Standard Kenworth diesel fuel tanks are made of aluminium. Each truck was provided with two 620 litre capacity tanks, mounted on either side of the chassis, with separate Emco - Wheaton filler necks and venting. (Figure III-22)

The work at Finning consisted of installing the methanol fuel tanks and lines along with all the methanol related electrical equipment. Vehicle fuel tanks were mounted on standard pannier style supports and the fuel lines to the engine replaced by PTFE hose with stainless protective braid.

The electrical work involved installation of the glow plug alternator control (GPAC), power distribution box, glow plug diagnostic box and wiring harness. The GPAC and power distribution boxes were fitted under the passenger seat and the glow plug diagnostic box was fitted on the dash. Glow plug operation prior to engine start-up was manually actuated by depressing a glow plug switch.

Sears
SEARS

Figure III-19. Williams Moving & Storage Kenworth W900 with Caterpillar 3406 Methanol Engine on the Trans-Canada Highway

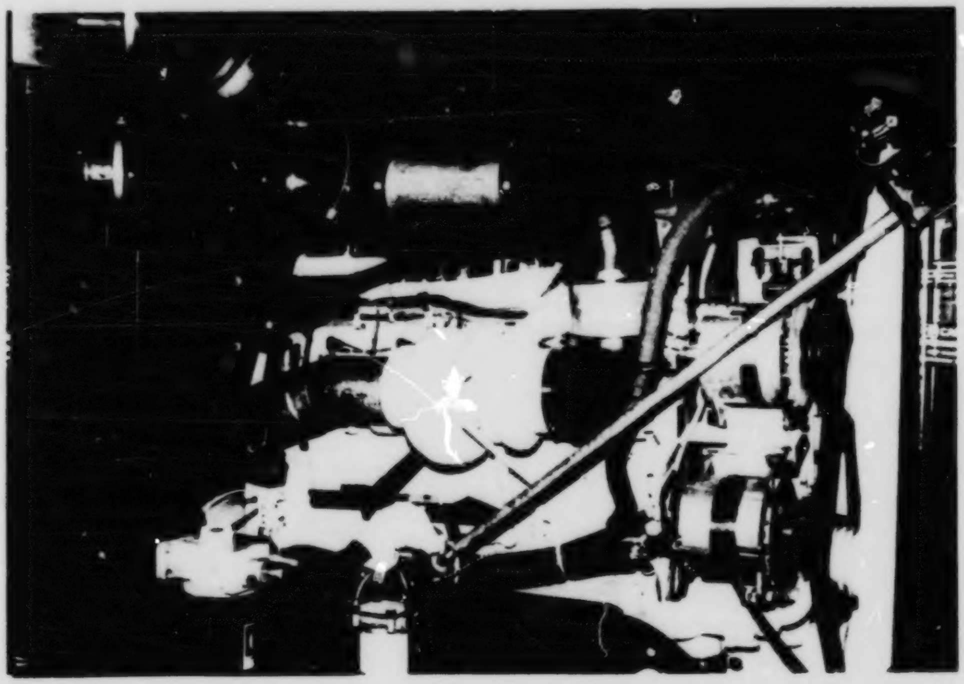

Figure III-20. RH Side of Caterpillar Engine Showing Extra Glow-Plug Alternator

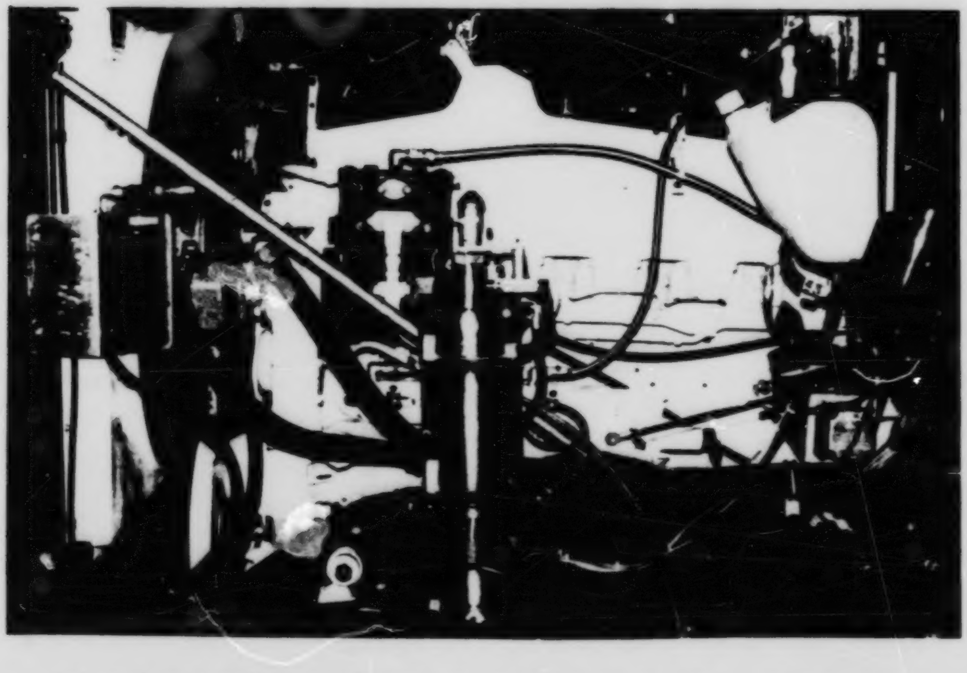

Figure III-21. LH Side of Caterpillar Engine Showing Fuel Pump Oil Reservoir

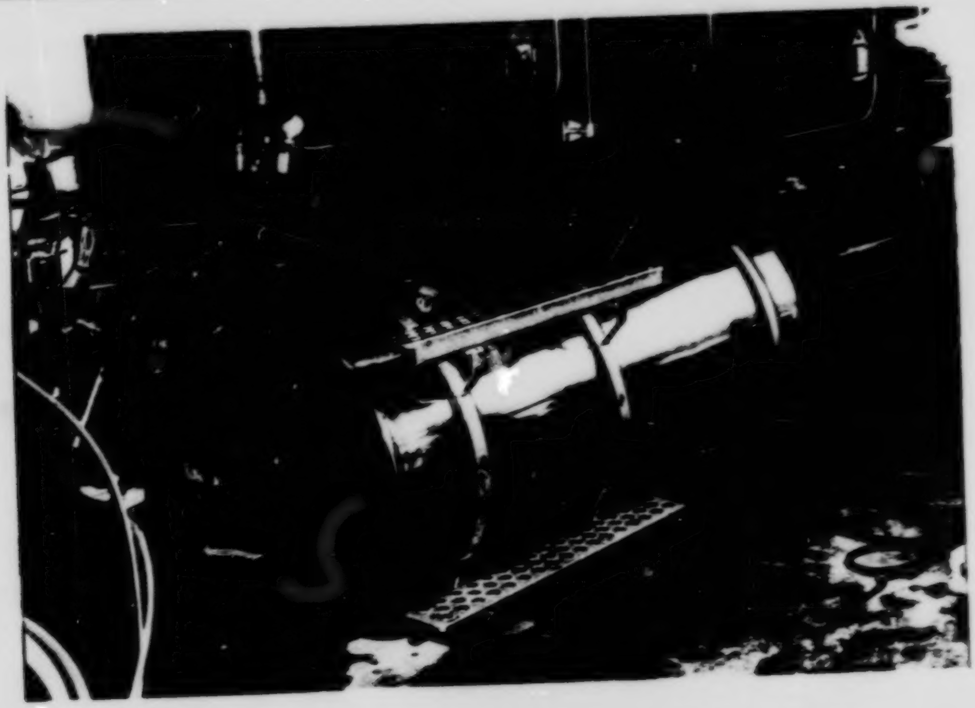

Figure III-22. Stainless Steel Fuel Tank for Kenworth Methanol Truck

Figure III-23. Kenworth Glow Plug Indicator Lights

The glow plug diagnostic box continually indicated individual glow plug status by six warning lights. (Figure III-23)

After completion of the work at Finning, all methanol related systems were functioning and the truck was driven to Inland Kenworth for final predelivery inspection and licensing.

Preplanning and liaison between the engine and chassis manufacturers indicated that methanol vehicles can easily be accommodated on an assembly line. If a methanol vehicle could be entirely built on an assembly line, many unnecessary delays could be avoided. Experience gained with this particular fleet indicates that this objective is realistic.

B.4 City of Vancouver

Figure III-24 shows the first of the two City of Vancouver methanol trucks.

The methanol conversions were carried out by Cummins, B.C. Ltd., the local Cummins dealer. The first conversion was particularly simple since the Freightliner chassis/cab had not yet been fitted with its garbage packer body. The Cummins methanol engine conversions were the most straightforward in the project. Only the diesel engine and fuel system required replacement. No ancillary electrical equipment was used.

The project vehicles were originally equipped with standard diesel L-10 engines. The L10 methanol engine is externally identical to the diesel version, and fitted right into the standard engine mountings. (Figure III-25 and Figure III-26) The original fuel lines were kept in place and capped. New stainless steel braided PTFE lines were installed. The original aluminum fuel tank was replaced with a 450 litre stainless steel tank.

A fuel cooler was installed on the fuel return line and mounted between the radiator and front grill. A fuel cooler was necessary because of the limited heat sink capacity of the single fuel tank. The Cummins engines, like the DDC engines, circulate a high fuel flow to the injectors with a large volume of heated fuel being returned to the fuel tank.

C. FLEET FUELLING

It was necessary to provide a fuelling station for each fleet, and 2 for the long distance truck fleet, making a total of 5 methanol fuelling stations which were built and placed in service as part of the MILE Project. All of the fuel stations were constructed with new components throughout.

The fuel used in the Project buses was 100% pure chemical grade methanol. The Williams Moving & Storage trucks had Caterpillar engines which ran with an addition of 1 part in 4000 of a corrosion inhibitor additive. The Cummins powered trucks in Vancouver used a blend of 95% methanol and 5% of I.C.I. "Avocet" combustion enhancer.

The fuel stations were commissioned at various times during the project duration, and operated with few major difficulties. Periodically, fuel samples were taken to check on contamination levels. Figure III-27 illustrates a typical fuel dispenser installed at the Williams main depot at Coquitlam, B.C.

C.1 Fuel Station Design

A fundamental target of Project MILE was to study and account for all aspects of the use of methanol as a fleet fuel. It was recognized from the outset that ease of vehicle maintenance and routine servicing is important to fleet operators, and particularly to transit operators faced with daily fuelling and servicing of hundreds of buses within a restricted time frame. It was also recognized that the MILE installation would be the only source of methanol fuel for the project vehicles, and must therefore be completely reliable and large enough to provide an adequate reserve of fuel in case of delivery delays. Obviously it was also necessary to pay attention throughout to the safety of the installation, particularly in respect of fire and personal exposure risks.

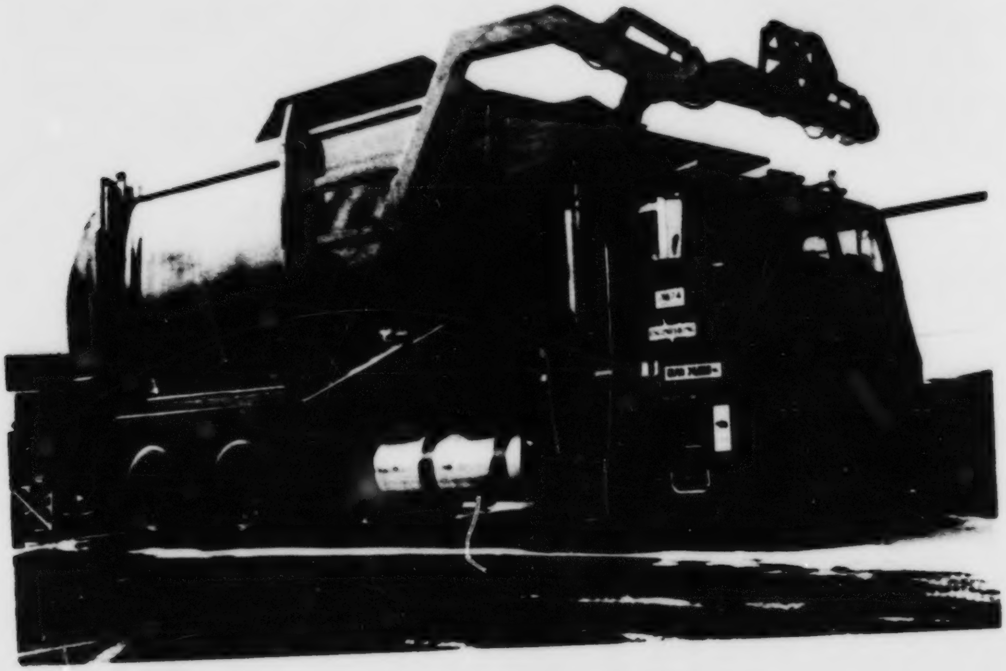

Figure III-24. City of Vancouver Methanol Truck

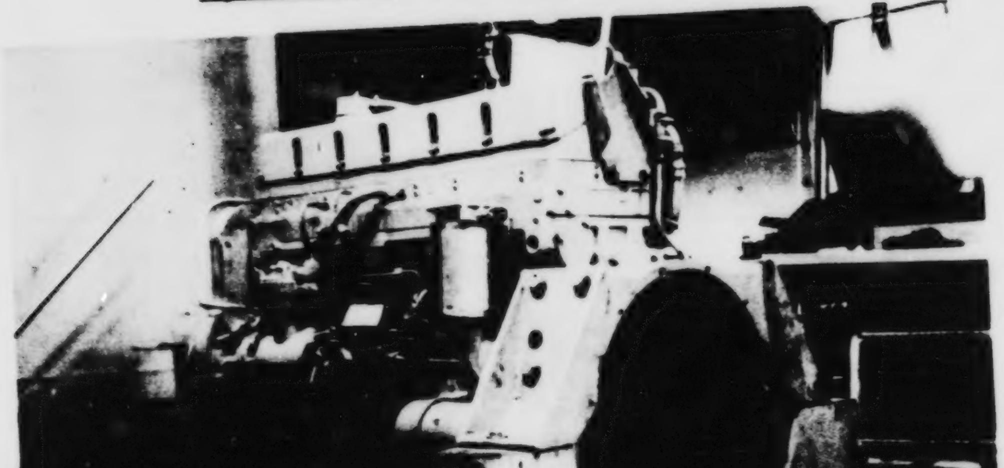

Figure III-25. Cummins Methanol Engine

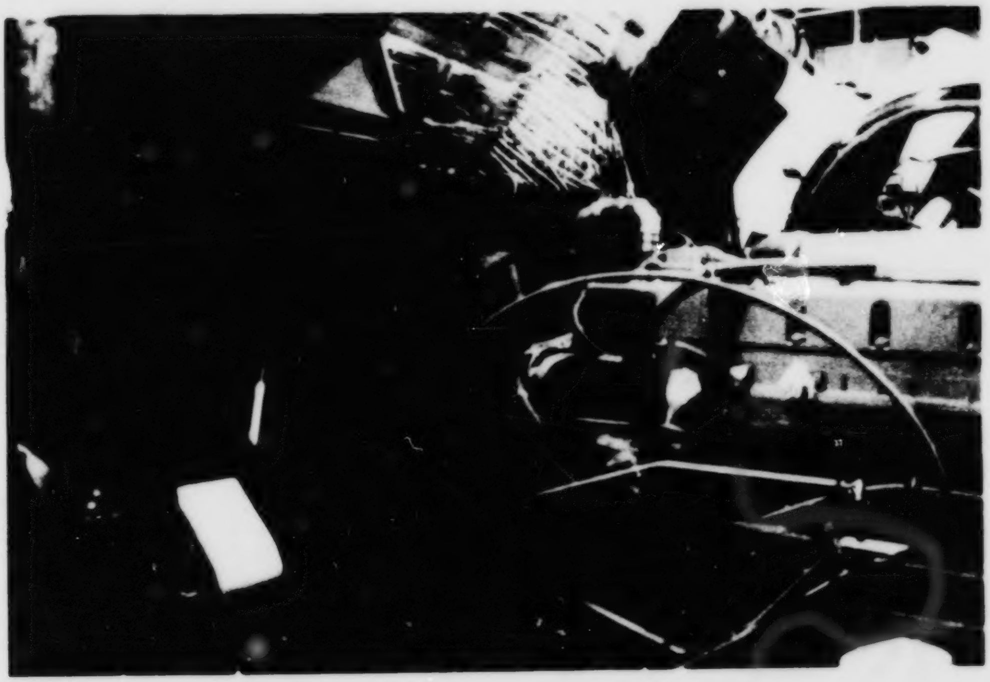

Figure III-26. Cummins Engine Installation

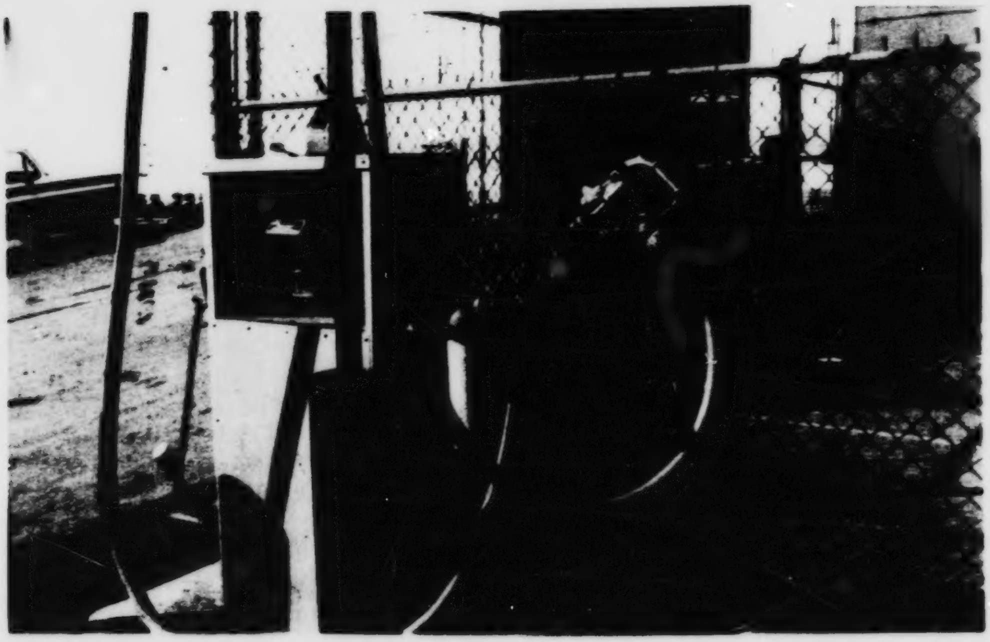

Figure III-27. Methanol Fuel Dispenser with Filter and "Dry-Break" Nozzle

Environmental and Fire Control authorities were consulted regarding the installations at the beginning of the design process and, in the absence of clear precedents, generally judged methanol fuelling to be comparable to gasoline. This allowed the design work to be set up along the lines of orthodox gasoline or diesel fuelling stations but meant that fuelling must be done outdoors. This is a handicap in Canada where many transit fleets store and service their buses indoors. However, only one of the fleets involved in Project MILE, Winnipeg Transit, fuelled indoors, and it was able to provide a site close enough to the bus storage barn to cause minimum inconvenience during fuelling of the two methanol buses based there.

A comprehensive specification was prepared for the fuelling station, but in view of time and budgetary restraints it was left to the contractors tendering for each site to specify equipment details, and to select their own component suppliers. This led to a diversity of designs, but also meant that the project accumulated experience with a variety of equipment from various manufacturers.

Figure III-28 shows the schematic layout of a typical project fuelling station.

All of the project installations shared the following features:

- Steel underground storage tank.
- High capacity delivery pump.
- Pressure/vacuum valve semi-sealed venting line.
- Fire control equipment.
- Emergency shower, eyebath and personal protective equipment for servicing crew.
- Emco-Wheaton Dry-Break delivery nozzle.
- Guard posts to protect dispenser unit.
- Integral tank level monitoring gauge.
- "Dedicated" truck offloading hoses to be kept on site.

A detailed explanation of each of the above components follows.

Storage Tanks

Tanks were sized to provide approximately one month fuel supply to project vehicles between deliveries, bearing in mind that volumetric consumption rates of methanol are over twice as great as those for diesel. This was felt to be a reasonable interval between fuel deliveries, and also a short enough time to give minimal chance of water or other contamination between deliveries of fresh fuel. Both bus fleets and the City of Vancouver truck fleet used 25,000 litre tanks. The Williams fleet was provided with two 50,000 litre tanks, one at each end of the run.

The tanks were all standard carbon steel cathodically protected types to the ULC standards S.603 and S.603.1. The decision to use steel tanks was based on the practice in the methanol producing industry, which uses large on-grade carbon steel tanks for bulk storage. Fiberglass tanks were considered, and the manufacturers offered assurances of the compatibility of their products with pure methanol. This type of tank appears to offer advantages in terms of longevity and reduced chance of contamination. However, the limited timeframe of Project MILE meant that any longevity benefits would be immaterial and so the extra costs of the fiberglass tanks could not be justified.

The tanks were buried primarily for the convenience of user fleets in terms of space and safety considerations. However, the underground location also gave a stabilized temperature situation which helped to minimize the generation and escape of methanol vapour from the vent system, and also helped to control humidity variations and consequent likelihood of water contamination or tank corrosion. No double walling, external containment or other anti-leak precautions were used since regulations at each of the sites did not impose such requirements. Tanks were externally protected by the mastic coating and sacrificial anodes specified as part of ULC standard S.603.1.

Fuel Pumps

The tank at Winnipeg was fitted with a Red Jacket model CP 150 1.5hp submersible pump, whilst that at Medicine Hat had a Tokheim 785-B-MC-PR pump situated in the dispenser cabinet. Of the other tanks, two used external pumps and one a submersible type. The pumps were all specified to deliver up to 200 litre/min, recognizing that to fuel with methanol in equal time to diesel requires at least twice the delivery flow rate. The Red Jacket pumps had a methanol compatible trim package, whilst the Tokheim pump was supplied as standard to accommodate alcohols and blended fuels. Both types proved satisfactory in service. The pump at Winnipeg had to be replaced after 11/2 years due to supply voltage fluctuations which damaged the motor armature, but no problems directly related to methanol occurred.

Pressure/Vacuum Venting

The tank vent pipes were extended to remote locations from the tanks in accordance with gasoline tank codes of practice. As an additional precaution against egress of vapours and ingress of atmospheric humidity the vent pipes were fitted with a pressure/vacuum cap which exhausted at 1 kPa pressure and admitted air at -0.5kPa. Therefore, the tanks were effectively sealed from the atmosphere except when filling or emptying, as the stable underground temperature minimized volume changes or vapour discharge at other times.

Fire Control And Emergency Equipment

Each fuelling station was provided with fire extinguishers, notices warning of both flammability and toxicity dangers, a supply of spill absorbant material, an emergency eyebath and a shower stall to wash off spills on the skin. Protective clothing supplied included gloves, boots, aprons and goggles or facemask. Where practical additional fire hydrants were installed to ensure an adequate volume of water to extinguish a methanol fire, which can remain flammable down to 20-25% concentration of methanol in water. The meter and dispenser cabinets were protected from vehicle damage by steel tube guard posts.

Dry-Break Fuel Nozzles

Emco-Wheaton positive locking dry-break fuelling nozzles were used on all of the fuel stations. They offered a number of important advantages, including the following:

- Flow rates up to 200 litres/min.
- No free vapour from filler neck when fuelling
- No "blow-back" due to air locking in filler
- No danger of over filling tank
- Minimal chance of spillage at start and end of fuelling

- Positive contact between vehicle tank and fuel dispenser before flow begins.

The Emco-Wheaton equipment was to be installed on all tanks from the start of the project, but because of queries regarding methanol compatibility and delivery delays the equipment was not used until late 1987. The fittings were mostly made of aluminum alloy, which is susceptible to attack from methanol. The components attached to the vehicle were specially nickel plated, but the fine tolerance in the delivery nozzle did not permit plating so the nozzles were used in stock form, with normal anodized finish. There were a number of detail problems with this equipment including wear and damage to the brass tank connector fittings, and need to balance flow rate against shut-off level settings to avoid fuel blow-out through vent fittings. The installation of the Emco-Wheaton nozzles made it possible to use the high pump outputs and fuel at up to 200 litres/min.

The danger of an in-tank explosion on the vehicle was reduced because the tank interior was never actually exposed directly to atmosphere during fuelling, and the tank to nozzle connection was made before the fuel flow began, so that any static electricity spark dissipated before fuel or vapour was present. Static grounding cables were also provided for connection to the vehicle during fuelling. Additionally, the vehicle tanks were fitted with drop tubes on the filler neck, which carried the fuel to the bottom of the tank and blocked immediate external access to the free air space above the fuel in the tank.

"Dedicated" Delivery Hoses

All methanol used in Project MILE was supplied at no cost by the Canadian Oxygenated Fuels Association, a consortium of the three primary methanol producing companies in Canada. It was delivered in road tanker trucks to the fleet fuelling stations by contract carriers, in trucks which may have been used for other chemicals. Although the trucks were cleaned between loads certain chemicals may have become absorbed into delivery hose materials, and then contaminated the methanol as it was off-loaded from the truck. Manitoba Research Centre experienced a case of chloride contamination traced to off-loading through hoses previously used for cleaning fluids. This led to sudden greatly accelerated wear rates in a Volkswagen methanol engine which was undergoing testing.

To eliminate this particular danger all MILE fuelling installations were equipped with a special set of tanker discharge hoses for exclusive use with project methanol fuel.

D. DATA COLLECTION

The project administration and data collection process was a three tiered structure beginning at fleet level, passing through an SMI regional coordinator assigned to each fleet, up to SMI headquarters in Ottawa where the master databases were maintained.

Each participating fleet was asked to nominate a prime contact person to be responsible for gathering the requisite data each day from within the fleet, and assembling it for forwarding to the local SMI coordinator on a mutually agreed schedule, generally each week. In order to simplify the task, existing fleet records and documentation were used whenever possible. When this could not be arranged the project provided standardized record forms for the data required including fuel consumption, mileage records, maintenance and servicing, driveability and oil sampling. The regional coordinator was responsible for ensuring the continuing flow of data, identifying gaps and discrepancies for correction, and acting as the immediate liaison between the fleet and other project participants, notably engine manufacturers, fuel and lubricant suppliers. SMI Headquarters staff travelled to the fleets for specialized data collection work such as dynamometer testing and field aldehyde sampling.

The project was intentionally conducted in the "real world" environment. This produced a much more valid test of vehicle capabilities, but accurate tracking of performance was much affected by the ability of the fleets to collect requisite data in the quantities and formats specified. Maintaining good data collection habits through periods of extended downtime was particularly difficult. The project staff obviously had no direct control over fleet employees and the system relied totally on the goodwill of fleet management, which was often severely taxed at such times.

The types of data collected included:

Daily Data

Distance travelled (km)
Fuel consumption (litres)
Oil consumption (litres)
Operational Status

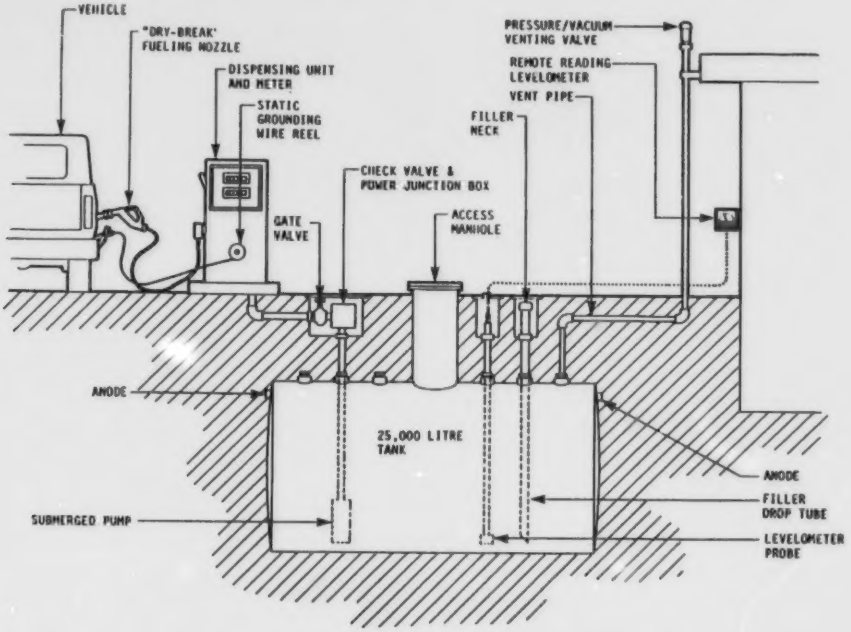
VEHICLE
"DRY-BREAK' FUELING NOZZLE
DISPENSING UNIT AND METER
STATIC GROUNDING WIRE REEL
CHECK VALVE & POWER JUNCTION BOX
GATE VALVE
ACCESS MANHOLE
FILLER NECK
PRESSURE/VACUUM VENTING VALVE
REMOTE READING LEVELOMETER
VENT PIPE
ANODE
25,000 LITRE TANK
SUBMERGED PUMP
ANODE
FILLER DROP TUBE
LEVELOMETER PROBE

Figure III-28. Schematic of Methanol Fuelling Station

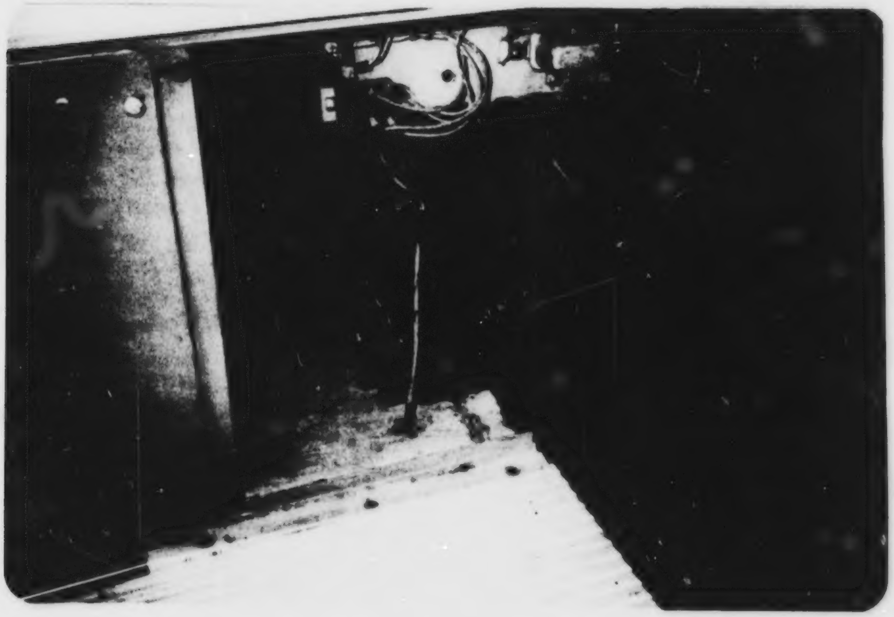

Figure III-29. Data Logger Unit Mounted In Bus

Driveability

Periodic surveys of the drivers' opinions on six aspects of engine performance were made, including:

Cold Starting
Hot Starting
Acceleration
Low speed performance (Under 50 km/h)
High speed performance (Over 50 km/h)
Transmission Shifting

In addition drivers were asked to record their overall impressions of the methanol engines.

Routes Travelled

Regular checks were made to ensure that test vehicles and control vehicles were operating on similar routes and duty cycles. All project vehicles in the Williams fleet operated over the same route. Winnipeg buses were traded off over many routes during the course of a day. Project buses traversed a composite of urban routes. In Vancouver the garbage trucks were alternated over different collection routes. Medicine Hat Transit operated six main routes and the methanol buses were used on each for a period of time.

Meteorological Data

Collected in areas where Project MILE vehicles operated in order to check for any correlation between the weather and performance.

Fuel Quality

Bulk fuel deliveries were sampled and tested for inorganic matter, water content and chlorides in order to detect potentially damaging contamination and ensure consistent fuel quality.

Maintenance Data

Methanol related breakdowns, repairs and modifications were recorded together with related costs when these could be accurately calculated.

Oil Analysis

Oil samples were taken from project engines at regular intervals depending upon fleet operations, to quantify how the lubricant performed in a methanol engine and provide insight, through wear metal analysis, into comparative wear rates between methanol and diesel engines.

In addition to the extensive manual collection of data, methanol and control vehicles were equipped with on-board electronic data loggers to measure ground speed and engine speed during daily vehicle operations. An appointed individual at each fleet loaded a fresh cartridge into each project vehicle at the beginning of the day. At the end of the day the cartridge was retrieved, and its contents electronically downloaded into a computer at the fleet office. Figure III-29 shows a data logger unit mounted in the front compartment of one of the Medicine Hat Transit buses. An automated telephone transmission procedure was used to transfer the data to the main database in Ottawa. Figure III-30 is an illustration of the project data flow network. Data was collected for a long enough period after commencement of operations to obtain a reliable indication of the daily operations of a vehicle.

Vehicles were also equipped with sensors, as required, to monitor engine and vehicle parameters such as exhaust, oil and coolant temperature, and fuel and air manifold pressure for use during periodic specia dynamometer and road testing sessions.

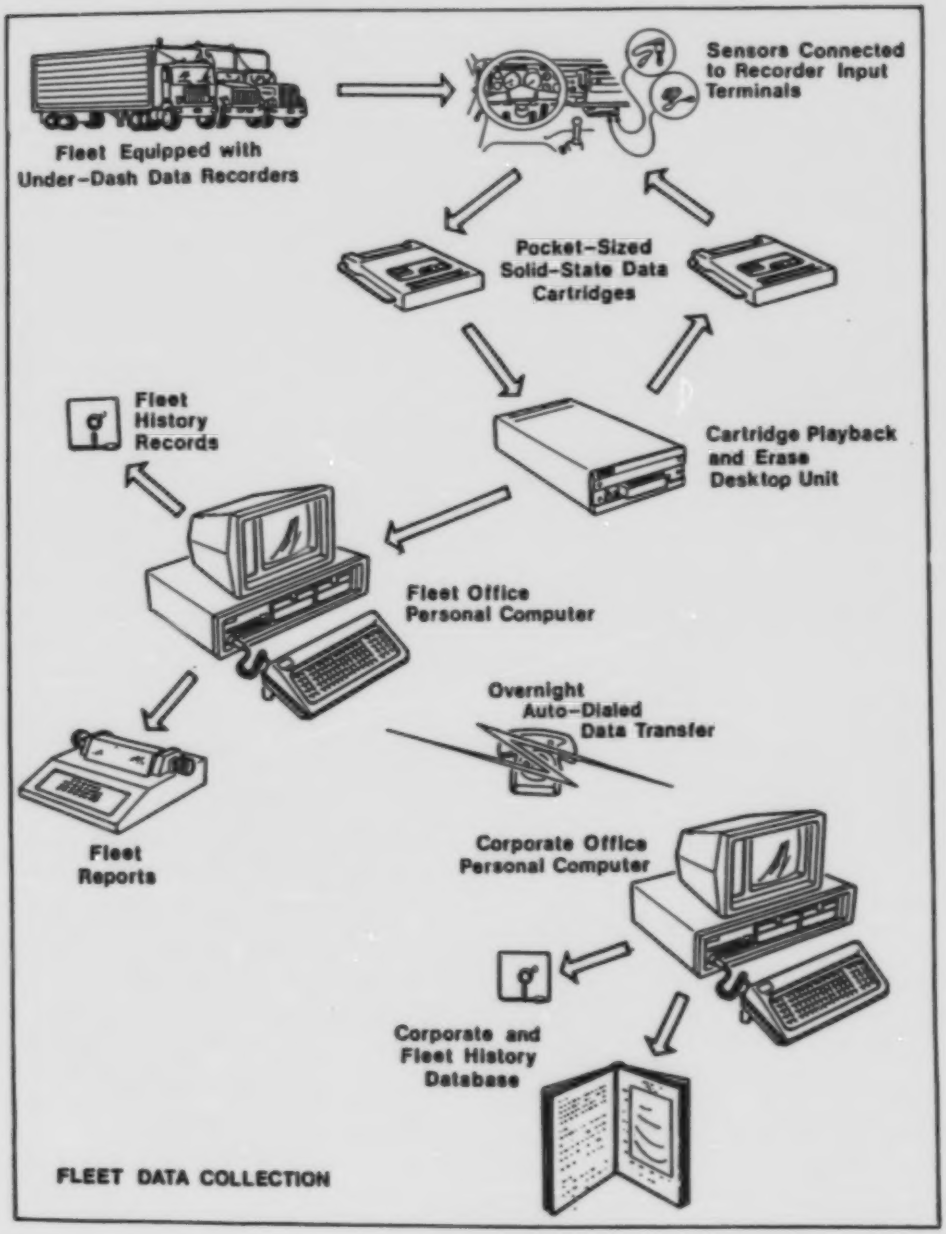
Fleet Equipped with
Under-Dash Data Recorders
Sensors Connected to Recorder Input Terminals
Pocket-Sized Solid-State Data Cartridges
Fleet History Records
Cartridge Playback and Erase Desktop Unit
Fleet Office Personal Computer
Overnight Auto-Dialed Data Transfer
Fleet Reports
Corporate Office Personal Computer
Corporate and Fleet History Database
FLEET DATA COLLECTION

Figure III-30. Electronic Data Collection Network

CHAPTER IV: OPERATIONS

A. WINNIPEG TRANSIT: FLYER-DDC BUSES

A.1 Cumulative Distance Covered

The two methanol buses at Winnipeg Transit started operations in November 1986 (bus 601) and February 1987 (bus 602). Figure IV-2 is a graph of the cumulative service distances achieved by the two methanol buses during the period February 1987 to September 1989. For clarity all units have been set at zero at the end of February 1987.

The methanol buses covered approximately 50% of the distance run by the diesel buses during this time period. The graphs show extensive periods out of service during the early part of the project. For instance, bus 602 recorded around 2,000 km during February 1987 but was then sidelined until July waiting for replacement injectors. The methanol mileage begins to mount up consistently after September 1988, when major engine upgrading work took place. This situation is illustrated more clearly in Figure IV-3 which shows monthly kilometers after September 1988.

Although total mileage accumulation was low prior to September 1988 there were several instances of good individual monthly performances, with nine reports in excess of 5,000 kms. The usual expectation for a diesel bus at Winnipeg is between 6,000 km and 6,500 km per month. Non-availability of spare fuel injectors caused the longest out-of-service periods. Detroit Diesel (at that time GM-Detroit Diesel Allison) had underestimated the requirement, and their supplier was unable to accelerate production. Attempts were made to repair the injectors at the local dealership, as is common practice for diesel components, but these were not consistently successful since at the time the specialist equipment and expertise required for the new electronic injectors was not available.

The engines, as originally supplied by Detroit Diesel Corporation, were prototype methanol variations of the 6V-92TA. There were many other instances for down-time while the manufacturer developed, obtained or supplied unique engine parts to the site. In addition, because the buses were virtually the first of their kind, there were many teething problems associated with installation of fuel delivery systems and electrical wiring configurations.

The general parts and servicing situation was further complicated by the business situation of Detroit Diesel at that time, which was not fully resolved until the company was reconstituted under the control of the Penske group on January 1st 1988. The new company quickly confirmed its commitment to methanol power and greatly increased the resources devoted to development work. The result was an intensive rebuilding of the project engines in August/September 1988. Figure IV-3 shows the greatly improved situation after the upgrading work. Bus 602 did not re-enter service until October, and since then neither bus has returned less than 2,000 km in any month.

The improved reliability levels made it possible to make the methanol buses available for general traffic duties as originally intended. Winnipeg Transit employed them on as wide a variety of routes as possible. Detroit Diesel Service staff carried out further detail changes to give better cold starting and idling based on experience gained as the project progressed.

A.2. Vehicle Operating Profile

Typical vehicle operating profiles were obtained in the early stages of the project. Figure IV-4 shows the distribution of road speed and Figure IV-5 shows the engine speed for a methanol and a diesel bus at Winnipeg Transit. The data were obtained from the on-board data logging units.

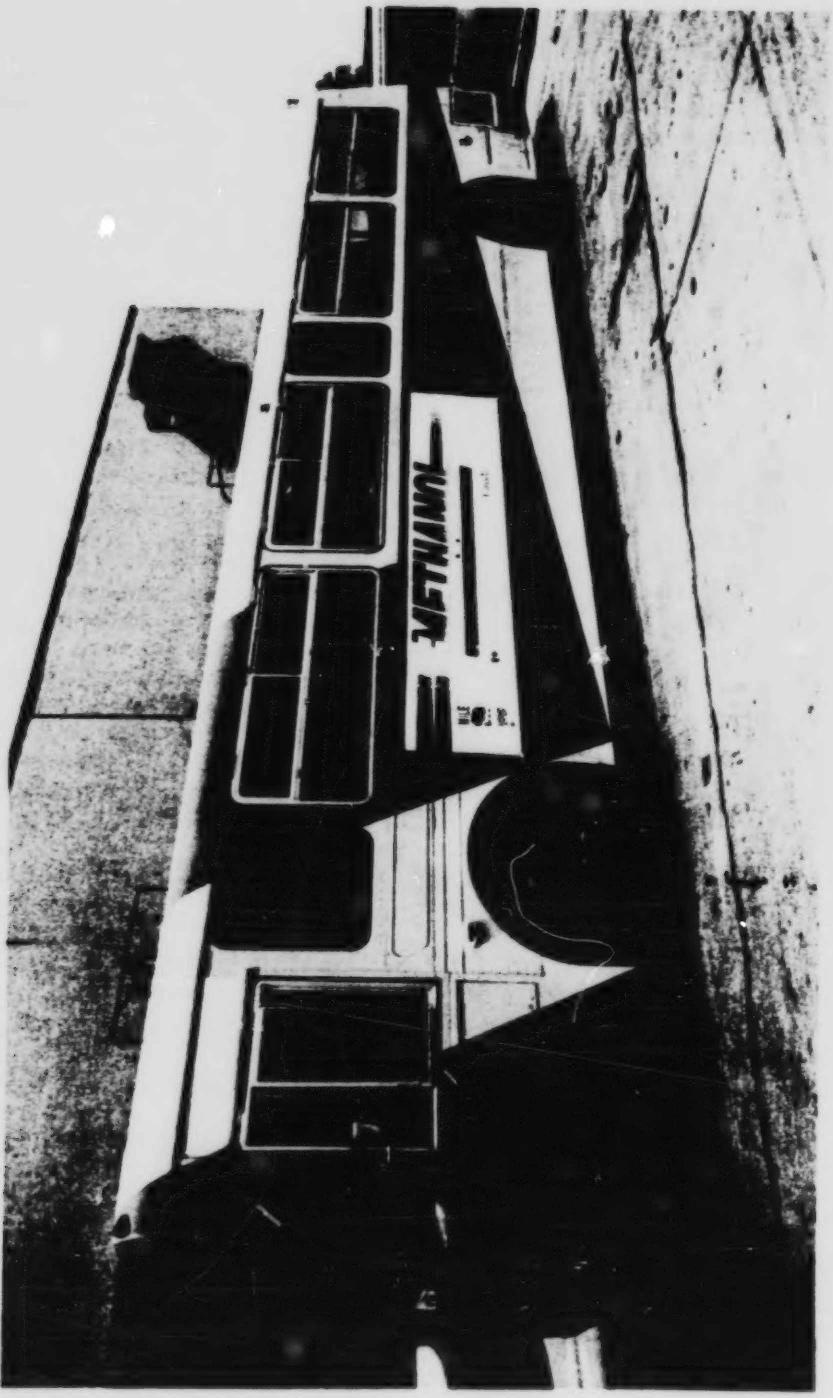

Figure IV-1. Winnipeg Transit Flyer Methanol Bus

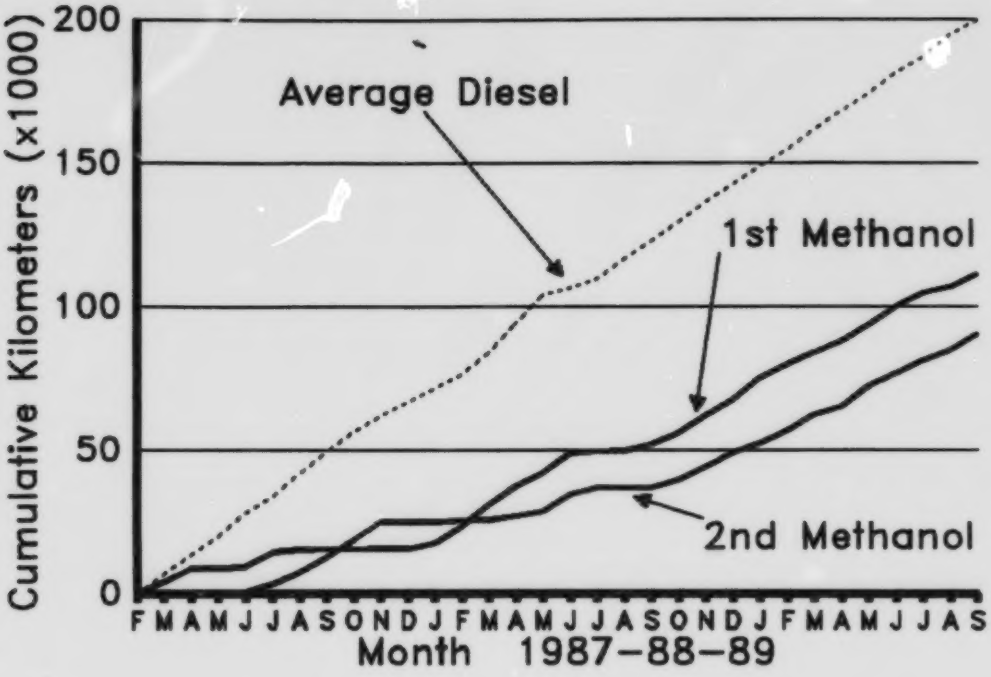

Figure IV-2. Cumulative Kilometers: Winnipeg Buses

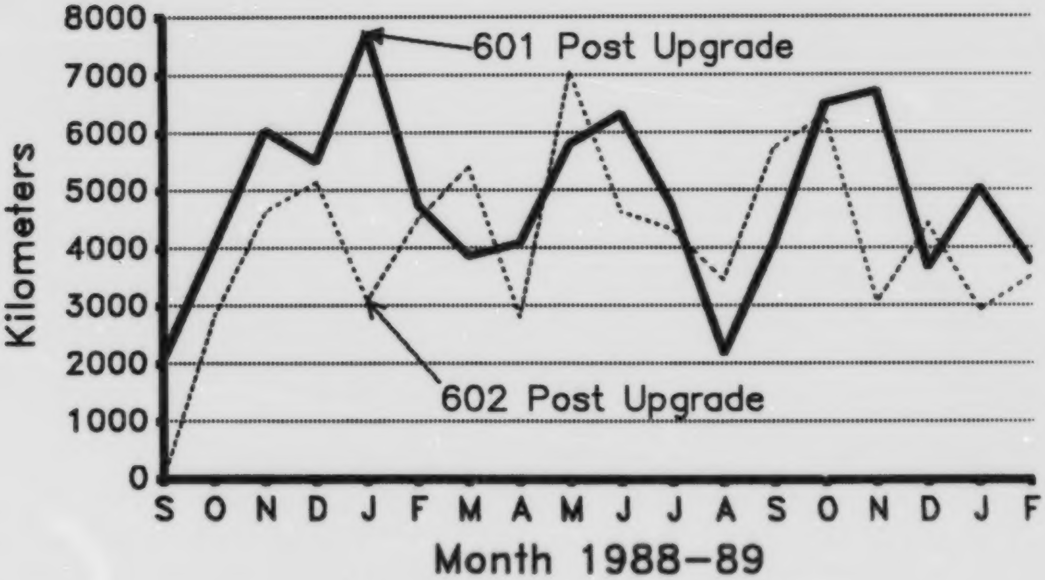

Figure IV-3. Monthly Kilometers: Winnipeg Methanol Buses

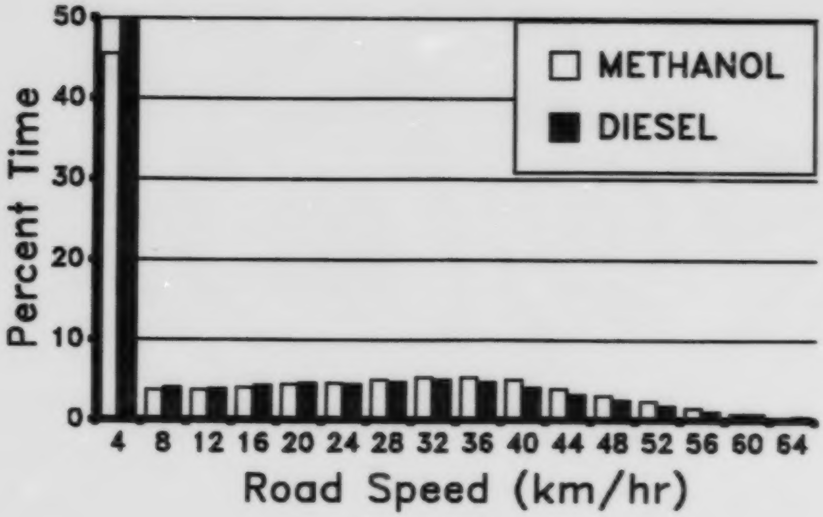

Figure VI-4. Road Speed Profile: Winnipeg Buses

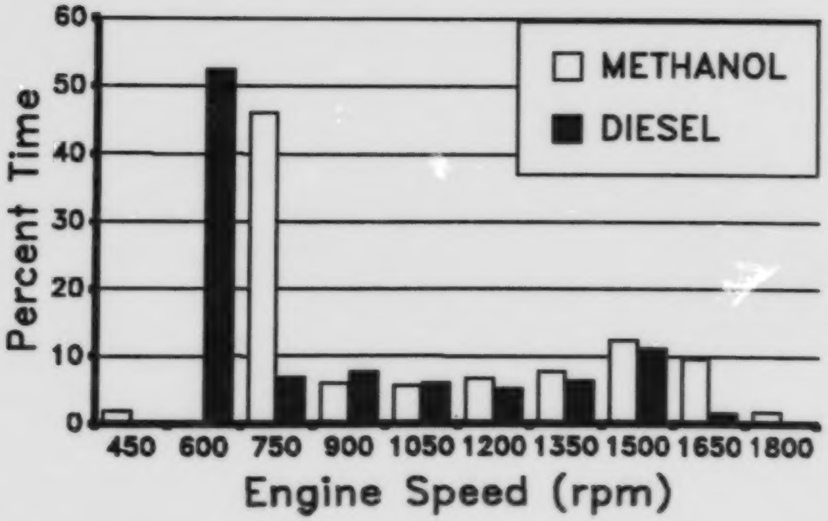

Figure IV-5. Engine Speed Profile: Winnipeg Buses

The road speed histogram illustrates very clearly the life of an urban transit bus, with almost half of the total operating time spent at a standstill or virtual standstill. No other speed increment band rises higher than 5% of total time, and almost all operation is at speeds below 40 km/h. The engine speed distribution follows the same shape very closely, with almost 50% of the time given over to the engine idle speed range.

The only clear difference between the methanol and diesel vehicles shows in the idle speed ranges, where the higher idle speed of the methanol engines is apparent. Normal diesel idle speed is 550 to 600 rpm, and the methanols were generally set in the 700 to 725 rpm range. This varied at times during the project, and a later modification to the methanol engines provided for two-speed idling, high speed when the engine was cold, automatically cutting speed back as it warmed up. The diesel buses have a high idle switch, a common fitting on Detroit Diesel engines, which can be used to maintain engine temperature and lessen oil consumption during prolonged idling periods. The first version of DDEC for the methanol engines did not provide this facility. The DDEC II package fitted in September 1988 included high idle, but it appears to have been used very little with either the methanol or the diesel engines. Although the aggregate engine idling time is very high individual stops are too short in duration for the high idle setting to be required.

A.3 Fuel Consumption

Prior to the engine upgrading work in September 1988 the monthly fuel consumption history was erratic. The average monthly methanol consumption rate was approximately 140 litres/100km. It was impossible to discern any meaningful pattern of consumption as a consequence of the frequent repairs and modifications carried out on the buses, as well as the normal variations due to driver and route changes.

The chart of monthly fuel consumption after the engine modifications work shows a marked contrast in results, (Figure IV-6). It is an indication of the far greater reliability of the buses as well as the general all-round performance improvement. Fuel consumption stabilized in the 150 to 160 litre/100km range for both buses. During the period under review the methanol engines were set to give 200 bhp at 2100rpm, the same rating as the control diesels.

Typical monthly fuel consumption rates for the two diesel control buses, 603 and 604, are also presented in Figure IV-6. The figures show the expected stable trend of diesel fuel consumption, corresponding to the high degree of mechanical reliability and service availability typical of a modern diesel transit bus

The volumetric fuel consumption ratio (methanol to diesel) at Winnipeg remained in the range of 2.6 to 2.8. DDC test bench work had given results closer to the theoretical 2.25 to 1 equal energy ratio. There was no formal attempt to improve the methanol bus fuel consumption during the reporting period. Engine modification work was directed to the more pressing goals of performance and reliability.

A.4 Influence of Climate

Methanol consumption at Winnipeg Transit eventually stabilized in the 150 to 160 litre/100 km range, and did not alter drastically during varying times of the year despite the severe winters experienced in Winnipeg.

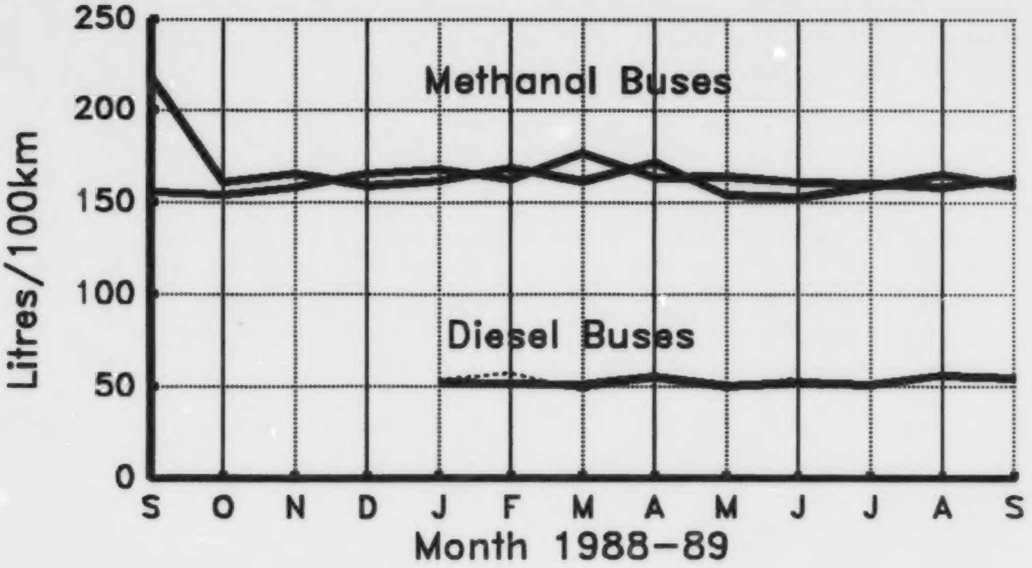

Figure IV-6. Monthly Fuel Consumption: Winnipeg Buses

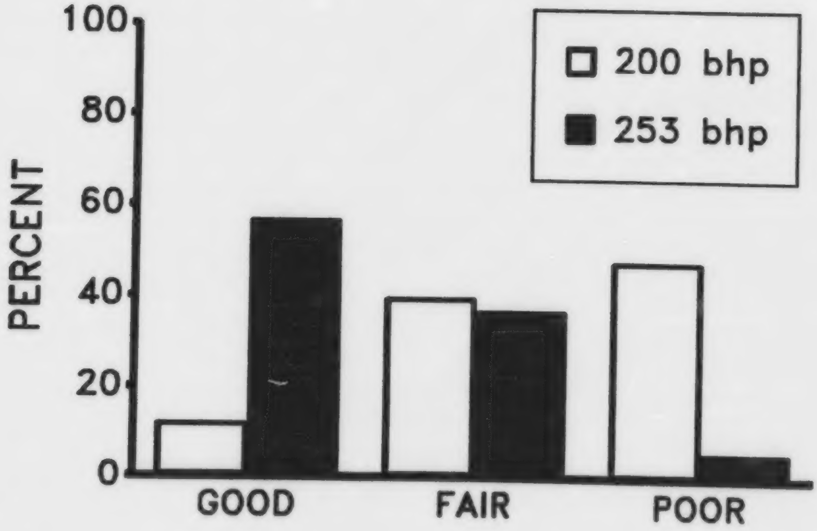

Figure IV-7. Driveability Rating: Acceleration

There was some initial apprehension expressed by the fleet management that the buses would not reach the same interior heat levels as the diesel buses because the engines were expected to run cooler than the diesels. Experience through 3 winters showed that the interior supply of heat for passengers was actually equal to or above that of other buses in the Winnipeg Transit system.

Theoretically, the cooler that methanol is used as a fuel the better because fuel energy density increases, but unlike diesel, methanol cannot become wax-like and clog fuel filters and lines. The methanol buses operated flawlessly during prolonged periods of -30C weather.

The methanol buses ran equally well during summer months when daytime highs were in the range of +30 to +35 C, with no sign of engine overheating or fuel boiling. No changes were made to the engine cooling systems at the time of the conversions and radiator, fan, hose sizes etc. were all as specified for the original 200 bhp 6V-71N engines.

A.5 Cold Starting

Cold Start tests were carried out at Winnipeg in March 1989 using methanol bus 601.

No special modifications were made for the tests. The lubricating oil was Paramins low ash SAE 40, the normal oil specified for the engines at that time.

The bus was first started indoors to establish a base case. Winnipeg Transit stores its vehicles indoors in a heated garage. At an indoor temperature of +19^{O}C, the bus started after a glow plug application of 60 seconds (normal time on the methanol engines) and a starter application period of 4 seconds. The engine required 2 minutes and 15 seconds to achieve a stable idle speed of 670 rpm.

The vehicle was driven outdoors and parked in an ambient temperature of - 19^{O}C. The windchill factor was 1750 watts per square meter and the relative humidity measured 65%. After four hours of cooling the engine temperature was - 8.9^{O}C. Eight successive attempts were made to start the engine under these conditions. No start was possible.

The following day two attempts were made to start the bus in an ambient temperature of -20^{O}C and windchill of 1800 watts per square meter. The engine temperature at this time was +35.6^{O}C following a cold soak of three hours. The engine had not cooled significantly internally and the second attempt was successful. Later on the same day two attempts were made to start the engine with an ambient temperature of -13^{O}C and engine temperature of +14.4^{O}C. The second attempt was successful. A new set of batteries had been installed the previous evening.

Finally tests were made in an ambient temperature of -17^{O}C with the engine temperature ranging from a low of -5.0^{O}C to a high of +7.2^{O}C. Six successive attempts to start the engine proved to be unsuccessful.

In summary, no start was achieved with the engine coolant temperature below +14.4^{O}C, with ambient air temperatures in the -13^{O}C to -20^{O}C range.

The engine control system was later modified to allow for better start-up capabilities. Detroit Diesel has demonstrated successful starts at -27^{O}C using more recent configurations in cold chamber tests. DDC expects that production versions of the methanol engine will have cold-starting capabilities superior to comparative diesels.

A.6 Engine Oil Analysis

The Detroit Diesel engines at Winnipeg had been in use for 115,000 kms and 95,000 kms respectively at the end of the period covered by this report. At that time they had achieved more continuous service than any other DDC methanol engine in transit fleet service. Winnipeg Transit commonly runs diesel engines to 500,000 kms before any major repairs are required.

The methanol engines went through four types of oil and one rebuild during the period under review. Initially regular diesel oil was used with disastrous results to injectors, which resulted in the change to low-ash formula oils supplied in succession by Texaco, Paramins and BP America.

Winnipeg Transit stated that its attempts at oil sampling had been affected by the high rate of oil consumption of some engines, which can occur in the situation where full power is seldom used and frequent idling is common. In these circumstances building the consistent comparable data which is key to long term assessment of wear trends was virtually impossible, and only broad conclusions may be inferred from the oil analysis work performed.

For the two methanol buses the most consistent set of data came from the period November 1988 to April 1989, when Paramins SAE 40 engine oil was in use. Sample analysis was performed by Paramins. The results are reported in Tables IV-1 and IV-2. Six samples were taken from bus 601 and five from bus 602.

During this period comparison samples were drawn from the diesel control buses. Four samples each for buses 603 and 604 were processed. Table IV-3 gives the results for bus 603, and Table IV-4 for bus 604.

These two set of results are not totally comparable since the local analysis service used for the diesel samples was unable to provide the same range of analysis as the Paramins laboratory service. The most significant wear indicator, iron, shows consistently higher for the methanol units. The tin content is also consistently higher, as are the copper and lead counts. The latter two metals can result from cooling system internal leaks as well as bearing wear, but such defects usually show up as spikes in the figures as opposed to a consistent level. The silicon figures are reported as a comparison of the potentially abrasive matter in the oil, the most common influence on silicon content being efficiency of inlet air filtration. Silicon content is also consistently higher for the methanol engines. T.B.N. (Total Base Number) figures were not available for the diesel samples, however it is reasonable to assume that TBN remains adequate between normal diesel oil change intervals.

Given that two widely differing types of oil were used, it is felt to be premature to attempt to draw conclusions from the results. Detroit Diesel believe that the iron content levels in the methanol engines resulted from corrosion of internal crankcase walls and other exposed areas rather than wear of liners, rings and other moving parts. The methanol engines were fitted with new liners, pistons and camshafts during the autumn 1988 upgrading work, and at that time wear levels were judged to be normal with the exception of piston slipper bushings and some localized cam lobe wear. The cam wear was probably due to the presence of debris in the oil, and the slipper pin bushings have been modified. The oil consumption rates for the methanol and diesel engines were not significantly different, and the methanol engines did not experience any wear-related failures or performance loss. Table IV-5 shows monthly oil consumption figures for methanol buses 601 and 602 during 1989. Units are kms/litre, and include only oil added during routine servicing.

Table IV-1. Methanol Bus 601 Oil Analysis Results (Exxon Paramins Oil)

Sample Date	Iron	Aluminum	Copper	Lead	Tin	Silicon	TBN
11/30/88	158	9	34	31	28	31	0.1
12/13/88	114	4	20	16	8	12	4.4
01/19/89	195	5	17	21	10	14	1.8
02/06/89	108	0	9	6	3	11	1.1
02/28/89	126	3	10	4	3	6	1.2
03/31/89	62	1	8	2	0	6	1.3

Table IV-2. Methanol Bus 602 Oil Analysis Results (Exxon Paramins Oil)

Sample Date	Iron	Aluminum	Copper	Lead	Tin	Silicon	TBN
11/22/88	68	1	16	4	14	19	0.1
12/21/88	117	0	19	10	10	20	0.1
02/01/89	60	1	12	6	2	14	1.1
03/10/89	60	0	15	52	11	12	0.2
04/05/89	151	0	24	62	5	16	0.2

Table IV-3. Diesel Bus 603 Oil Analysis Results (SAE 40 Conventional Diesel Oil)

Sample Date	Iron	Aluminum	Copper	Lead	Tin	Silicon
01/12/88	25	2	6	2	0	4
04/03/88	26	3	3	4	0	5
08/17/89	35	3	3	4	0	8
09/17/89	42	3	4	5	0	10

Table IV-4. Diesel Bus 604 Oil Analysis Results (SAE 40 Conventional Diesel Oil)

Sample Date	Iron	Aluminum	Copper	Lead	Tin	Silicon
01/11/88	49	5	26	7	0	10
04/03/88	12	1	3	1	0	1
08/17/89	28	3	3	3	0	8
09/17/89	32	3	5	5	0	10

A.7 Driveability

One original intention of the project was to receive ongoing assessments of driveability through continuing driver surveys. Unfortunately the early performance and reliability problems experienced with the buses quickly negated the value of this exercise, since it became obvious that the ratings would be consistently low and would unfairly bias any assessment of the potential of the methanol buses, as opposed to their early shortcomings. It was accepted that the buses were capable of good performance under load when everything was working properly, but engine idle quality was always inferior to diesel and the engines also tended to cut out unpredictably when stopping suddenly.

A decision was made to suspend driveability data collection until these faults had been overcome. The September 1988 upgrade work provided the opportunity for reassessment, and by spring of 1989 the two buses had begun to live down much of their earlier reputation. This was therefore judged to be an appropriate time to gather a fresh set of driveability data. A survey was conducted from May 15 through to July 15 of 1989.

There were a total of 163 responses by the drivers (88 from bus 601 and 75 from bus 602) with the participation of 123 drivers. Some drivers operated the buses on more than one occasion. The buses were utilized on all types of route in the Winnipeg Transit system, urban, highway, residential, and express.

In general the drivers were not pleased with the poor acceleration of the methanol buses. Part of the problem was found to be related to driving methods. At the time 601 and 602 were the only two buses in the Winnipeg fleet equipped with DDEC engine control systems. Many drivers, when leaving a stop, typically pressed down on the accelerator while the rear door brake interlock was still applied. As soon as the brake interlock released the bus accelerated away. The DDEC system required that the accelerator be returned to the idle position to re-index the full engine rpm range, if the driver held the pedal down full power was not available. Pointing this out to the drivers solved some of the complaints.

Later on a series of acceleration tests were conducted with buses 601, 602 and one of the control buses, 604. One driver and one test point were used for consistency, and runs were made in both directions.

The results obtained are shown in Table IV-6. (A) represents times with a tailwind; (B) represents headwind times.

The tests showed that, even without the rear door interlock and the DDEC situation, buses 601 and 602 were slower to accelerate than the control diesel bus. After discussion with Detroit Diesel Corporation, a decision was made to increase the power rating of the methanol engines to that used in other DDC methanol fleets. On September 23, 1989, the EPROM on both buses was reconfigured to give 253 bhp. No mechanical changes were necessary. Acceleration tests were conducted again with buses 601 and 602. The new results are shown in Table IV-7. The improvements in acceleration are apparent.

With this new power rating, a second driveability survey was conducted from September 25 through to November 4, 1989. There were 130 trip reports submitted from 111 drivers. 24 of the drivers had been involved in the first methanol evaluation process. Figure IV-7 shows the ratings for acceleration before and after the power increase.

Table IV-5. Methanol Bus Oil Consumption (km/litre)

Bus No.	Month (1989)										
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
601	516	366	644	1020	1161	1055	429	728	827	342	374
602	770	900	541	936	642	926	1082	3439	1905	2104	1531

Table IV-6. Acceleration Times - Methanol and Diesel Buses

	0-30 km/h	0-60 km/h	0-80 km/h
Methanol	9 sec	31 sec	60 sec (A) 76 sec (B)
Methanol	10 sec	32 sec	62 sec (A) 78 sec (B)
Diesel	9 sec	27 sec	56 sec

Table IV-7. Acceleration Times - Methanol 253 bhp Rating

	0-30 km/h	0-60 km/h	0-80 km/h
Bus 601	9 sec	22 sec	38 sec
Bus 602	9 sec	22 sec	39 sec

During the initial survey period, some of the comments were:

" These buses should never be put on routes like #75, #78, #62X, #21X - they're much too slow pulling into traffic on high speed roads."

"The only problem I find is that the bus rear door interlock is slow to release and that acceleration when taking off from a stop is slow at first."

"Very poor acceleration; sometimes there is no acceleration until the accelerator pedal is depressed twice."

"I would consider this bus actually unsafe to operate in city traffic for reasons of very poor acceleration."

"Very slow pulling away from stop. Being so slow makes changing lanes or pulling in and out of traffic unsafe at times."

"Too slow in taking off. No power at all."

"I've had trouble with the interlock, but learned to wait then accelerate."

"I find the incredibly slow acceleration to be a definite safety hazard as well as a terrible annoyance to the operator."

"Wouldn't take the skin off a rice pudding."

The candidness of the drivers did not change following the upgrading of horsepower, but their attitude towards the buses, particularly the acceleration, did:

"On a route like Pembina, you have to be quick. With the added acceleration of this bus, you have a vehicle that you can have confidence in to help keep you on time."

"Much improvement, runs extremely well, lots of pickup and you can maintain a schedule. Thank Heaven for mechanics that know what they can do."

"Very fast bus; pleasure to drive."

"Bus has much better acceleration than before. Hats off to those responsible!"

"Overall driveability is excellent except for when accelerator is quickly applied before rear door interlock is fully released. This vehicle operates far better than the last time I drove it, power is much better, comes on sooner and is very smooth."

"Superb pickup. It would be nice if all buses had fast take-offs."

The question of acceleration performance generated the most comment and interest during the driveability surveys. Drivers were also asked to comment on the full range of engine performance features. The following series of figures illustrates graphically the results of the other sections of the survey. A "poor" rating indicated definite inferiority to the normal level of diesel performance, "fair" indicates an acceptable level generally equal to a diesel engine, and "good" denotes definitely equal or superior to diesel standards.

Cold starting is dealt with separately in section A.5. Figure IV-8 illustrates the assessments given to this category in the two driveability surveys.

Figure IV-9 gives the Hot Starting assessment. This was the only classification in which the September ratings are inferior to those of the earlier survey.

It is possible that the methanol engines will never receive high ratings for ease of starting from drivers as long as there is a need to wait for several seconds for the glow plugs to warm the cylinders. The buses were started indoors in normal operations and generally would not be shut down until the finish of the days operations.

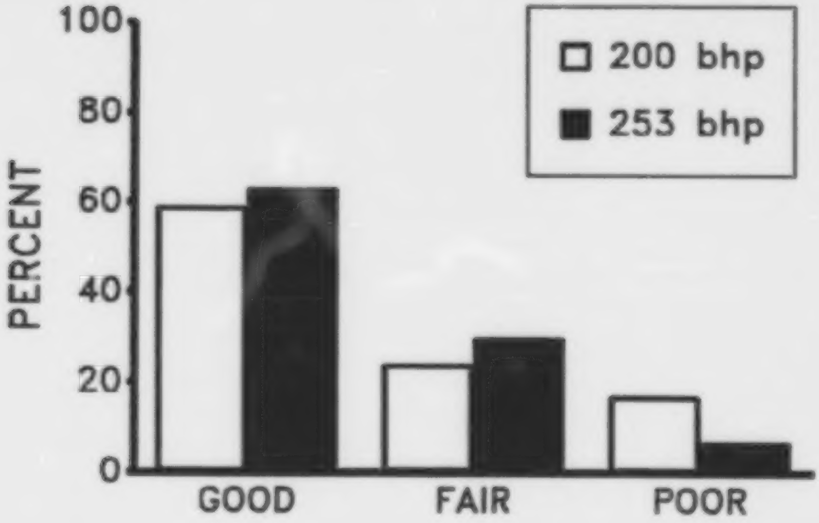

Figure IV-8. Driveability Rating: Cold Starting

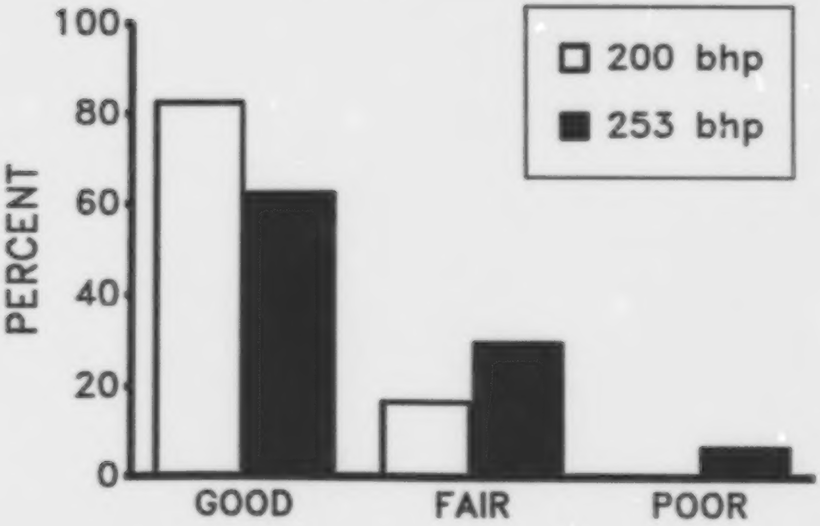

Figure IV-9. Driveability Rating: Hot Starting

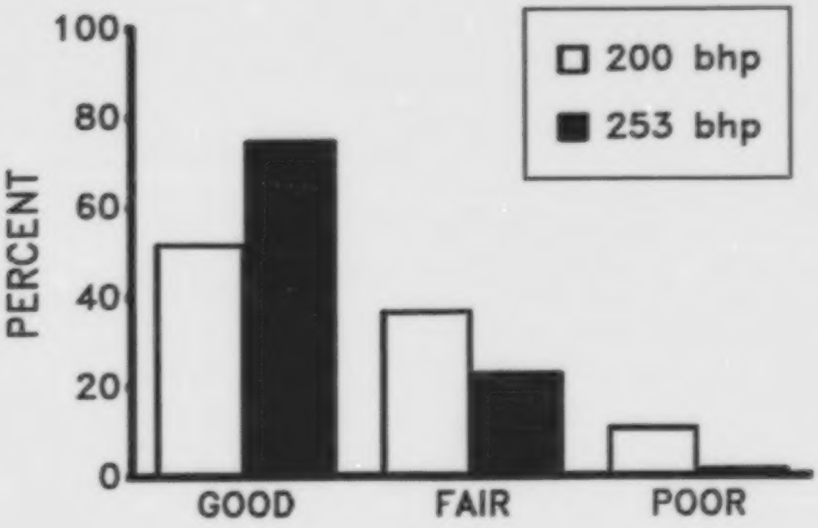

Figure IV-10. Driveability Rating: Engine Idle

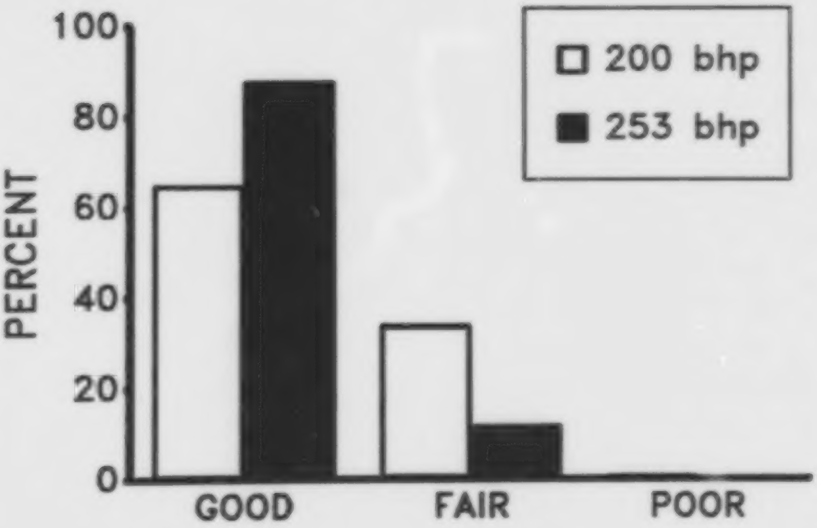

Figure IV-11. Driveability Rating: Over 50km/hr.

Figure IV-10 shows the engine idle quality scores. Engine idle quality was one of the weaker features of the bus engines at Winnipeg, particularly when starting from cold. In the early stages of the project the engines would misfire and vibrate severely on starting, and the idle would not smooth out until they were well warmed up. DDC recognized the need for improvement, and devoted a corresponding amount of time to changes in DDEC configuration, blower by-pass air control and glow plug modulation in order to achieve an acceptably smooth idle under all normal conditions.

The later engine configuration was close to matching diesel standards, although it was still necessary for idle speed to be 100 to 150 rpm higher than a diesel. In addition, a modulated idling feature for cold starting set the initial cold idle approximately 100 rpm higher still, and progressively reduced the speed in response to engine coolant warming. This feature was effective in reducing the amount of unburned methanol emitted during cold starts as well as preventing the noise and vibration attendant on misfiring.

The assessment of general on-road performance was divided into driving above 50km/h and driving below 50km/h. This was an attempt to isolate a potentially weak area of operation, low speeds and light loads. Generally, throughout the project, the methanol engines were at their best when working fairly hard and keeping well up to operating temperature. This was the case at all stages of development and for all three types of engine used in the project. Figure IV-11 is the chart of the over 50km/h performance. The "good" rating rose from 65% before the engine power increase to 87% afterwards, one of the highest rated categories. Under load the methanol engines pulled smoothly and strongly.

The corresponding chart for under 50km/h driving is given as figure IV-12. As implied above, the ratings are lower, and for the first survey the combined total of "fair" and "poor" ratings exceeded the "good" figure by a considerable margin (55% against 45%). This was the second lowest rated classification after acceleration. However, the "good" rating was boosted to 73% following the engine power boost, and the "poor" rating reduced from 17% to only 1%.

Comments on transmission shifting quality were invited in an attempt to study the engine's reaction to the sudden changes of load and speed involved, whether the engine would stumble or hesitate in picking up power, or hunt excessively before stabilizing at the new rpm level. All buses involved in the project used Allison 3 speed automatic transmissions, buses at Winnipeg having the newest electronically controlled version. The drivers therefore had little or no influence on transmission shifts, and such comments as they could make inevitably reflected on the transmission as well as the engine. Figure IV-13 shows the numbers obtained.

During 1987 some of the engine stalling problems were found to be associated with the matching of the engine and transmission. The direct drive cut out speed setting was too low for the methanol units. At that time there was little general experience of matching an electronically governed engine to an electronically controlled transmission, and none whatsoever for a methanol fuelled engine. Nevertheless shifting was not perceived as a problem with a final 83% "good" rating and 0% "poor".

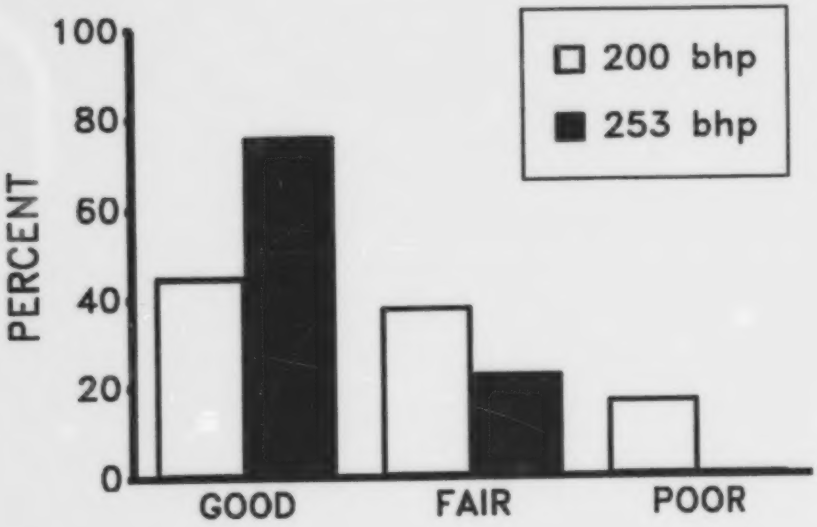

Figure IV-12. Driveability Rating: Under 50km/hr.

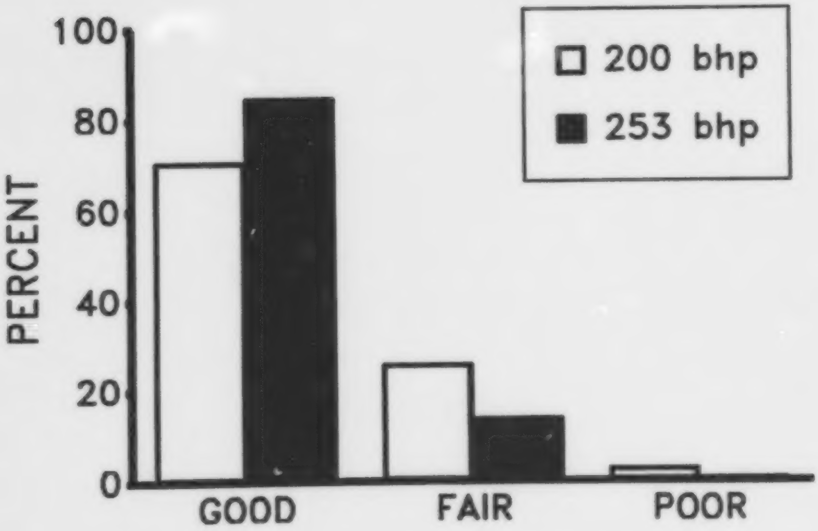

Figure IV-13. Driveability Rating: Transmission Shifting

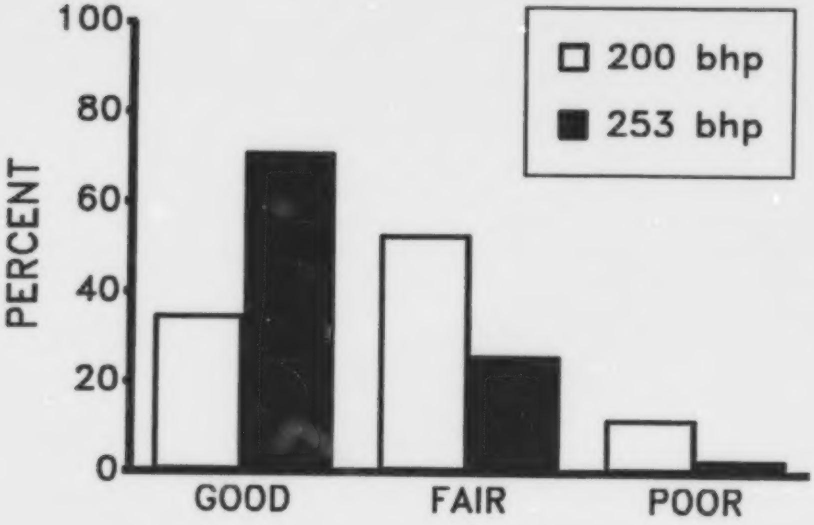

Figure IV-14. Driveability Rating: Overall Assessment

Medicine Hat
POWERED BY
METHANOL

Figure IV-15. Medicine Hat Transit Methanol Bus

The final figure in the series, Figure IV-14, was the response to the overall assessment question. This was only 35% "good" in the first survey, and was heavily biased by the dissatisfaction with acceleration. The second survey doubled this percentage to 71%. Bus and truck drivers have a natural tendency to look for more and more power, but it is clear that good acceleration is important in heavy traffic conditions, and for maintaining schedule times on multi-stop routes. The fleet in general was impressed by the fact that the methanol engines had reached a stage at which deficiencies could be effectively dealt with in an expeditious manner, in response to operating requirements.

A.8 Fleet Attitudes

Winnipeg Transit, in the early part of the project, suffered through some very unsettling times with the buses. Obtaining spare parts was not always easy. The buses were equipped with items such as the DDEC system and glow plugs that were totally unknown to the maintenance staff. For a long time the majority of diagnostic and rectification work was performed by dealer staff, DDC representatives, and/or a member of SYPHER:MUELLER's project management team. Availability and reliability could not be maintained at satisfactory levels. The fleet on a number of occasions seriously considered withdrawing from the project. The major factor influencing the situation at the time was the business status of the Detroit Diesel Allison Corporation, which was negotiating with a potential new owner and consequently in no position to supply the support required for the project. The project management could do nothing to control this unpredictable state of affairs, which was not resolved until the January 1988 takeover by Penske Corporation. (Not the original potential buyer). The new Detroit Diesel Corporation moved quickly to get methanol development back under control and appointed new staff specifically to deal with the two MILE fleets.

The supply of parts at Winnipeg Transit was reorganized and replenished so that known high-use items were on hand. Manufacturer support was made readily available. DDC representatives contacted Winnipeg maintenance staff on a daily basis to ascertain the operational status of both buses; this same process was performed by SYPHER:MUELLER's regional representative. A very close working relationship developed between Winnipeg Transit's maintenance staff, Detroit Diesel Corporation and SYPHER:MUELLER International to resolve, immediately, issues affecting the operation of the engines.

Drivers attitudes and perceptions are examined under section A.7. The attitude of the maintenance staff towards the buses was at first considerable interest and curiosity. Initially it was not possible to hand over the maintenance of the buses to transit staff because there was no repair experience or expertise to pass on, and the only work which could be done was routine servicing. This was mildly disruptive because of the fire and safety precautions necessary, and under these conditions much of the early interest evaporated. The fleet provided appropriate warning signs to display when the buses were in the workshop, and this unfortunately tended to arouse a certain level of suspicion among workers. Later in the project, when the total maintenance program was passed to transit staff, a select team was assembled which quickly familiarized itself with most of the common faults and in particular with use of the DDEC diagnostic equipment. By 1989 Winnipeg Transit maintenance staff had totally taken over the task of diagnosing and rectifying problems with the engines. This experience helped the fleet when it received deliveries of new diesel buses equipped with DDEC II. Additionally methanol engines have always been equipped with turbochargers. Winnipeg Transit recently received the first turbocharged diesel engines in its fleet.

The experience gained in working on the methanol engines therefore effectively introduced maintenance staff to features which are standard on new diesel engines and buses.

The fuelling and daily servicing crew were affected more than any other group by the introduction of the methanol buses. Due to the fire safety regulations the buses had to be fuelled outdoors. All other Winnipeg Transit buses were fuelled indoors in a drive-through servicing lane. The buses were cleaned and fueled, engine oil and transmission fluid were topped up, and then the buses were parked in an indoor garage ready for assignment. The need for fueling outdoors upset the servicing sequence. Additional time was required to drive the bus over to the methanol fuel pump, and the service man had to wait with the bus while it was fuelling before taking it back to the storage garage. Fortunately it was possible to construct the methanol fuelling station close to the general servicing and parking areas, and the impact of 2 buses in several hundred was minimal. However, there is no doubt that indoor fuelling would greatly increase the acceptability of the methanol buses to Winnipeg or any other sizeable Canadian bus fleet.

A recurring topic of considerable consequence to fleet management was the question of exhaust gas aldehyde levels. When the buses are started at the beginning of their shift, they are warmed up indoors. The project portable aldehyde test device was developed to address this issue. Testing was carried out at Winnipeg and gave aldehyde levels 1.5 to 2 times as high for the methanol engines as for the diesels. This conflicted with some reports of comparisons carried out in laboratory test cells, when the ratio was found to be much higher. More tests are required. The situation is very fluid. Engine design is advancing continually. Aldehyde test apparatus is not yet fully developed, and there is no generally accepted data regarding safe ambient aldehyde levels or methods of measuring same. Chapter V of this report addresses the topic in more depth. The situation may be summarized by saying that the fleet was very wary regarding aldehyde emissions and would definitely require some authoritative statements on actual exhaust levels, safe ambient levels and reliable testing of both before ever considering a large-scale move to methanol power.

The Winnipeg fleet passed through phases of initial interest and open-mindedness, increasing skepticism and loss of confidence almost culminating in withdrawal from the project, back to a readiness to give the buses a second chance in view of the demonstrated all round improvements in reliability and serviceability. However, there are several very important factors to address before it would consider using more methanol vehicles including indoor fuelling, exhaust emissions and the economic implications of such a move.

B. MEDICINE HAT TRANSIT GMC - DDC BUSES

B.1 Cumulative Distance Covered

The two buses at Medicine Hat Transit began in operations after those at Winnipeg, bus 754 entering service at the beginning of 1987 and bus 759 in the third quarter of the same year. By September of 1989, bus 754 had accumulated 57,000 kilometers and 759 had accumulated 33,000 kilometers. Figure IV-15 shows bus 754 in the distinctive Medicine Hat Transit delivery.

Figure VI-18 shows the comparison of cumulative distances attained by the two methanol (754 and 759) and two control (757 and 758) buses throughout the project to September 1989.

Figure IV-16 shows the monthly kilometers for the methanol buses comparison after the autumn 1988 engine upgrade work.

It is very clear from these figures that bus 754 saw very little service during its first year of operation, and that bus 759, following an initial spurt in late 1987, rapidly deteriorated in performance. In 1988 the methanol buses were essentially out of service all year.

There were a number of reasons for this. The general dearth of factory service and spares support in the early days was a major factor. The other sources of assistance, the dealer who carried out the conversion work and the SMI regional co-ordinator, were both in Winnipeg. There was no spare manpower to spend time over methanol problems, and in the absence of speedy and conclusive fault diagnosis the only course of action open to the fleet was to park the methanol units and put spare diesel buses into service. The low-water mark of performance in 1988 was very largely due to the drying up of the supply of spare fuel injectors. In 1987 a lack of spare injectors delayed the conversion of bus 759 by over 3 months.

The engine upgrading work unfortunately did not produce the same immediately improvements which were experienced at Winnipeg. The methanol engines began to show high rates of injectors failure, some failures occurring almost immediately after installation. A break in procedure was devised in an attempt to alleviate this problem. However, the failures continued particularly with injectors on the right hand cylinder bank. The injector plunger would typically become sticky in action or seize up completely.

Diagnostic work revealed high exhaust back-pressure levels, up to six times the recommended value of 1 in. (Water). The modified exhaust system was restricting exhaust gas flow and causing high in cylinder temperatures. The excessive restriction had not been apparent before engine upgrading because at that time the engine was rated at only 200 bhp. Medicine Hat Transit requested an increase to 277 bhp., the higher of the two proposed production ratings for the 6V-92TA methanol engines, in order to bring performance up to the standards of its newer diesel buses. The modified exhaust system was too small for the higher air and gas flow rates involved. The exhaust system was rebuilt during April 1989. Modified injectors were also introduced during the summer, and by August 1989 the two methanol buses were both performing consistently.

Figure IV-17 shows that bus 754 returned several months in the 4,000 km to 4,500 km range. The diesel control buses normally ran between 8,000 km and 10,000 km per month, operating 6 days per week. The methanol buses were used only 5 days per week because no staff were available to fuel them on Saturdays.

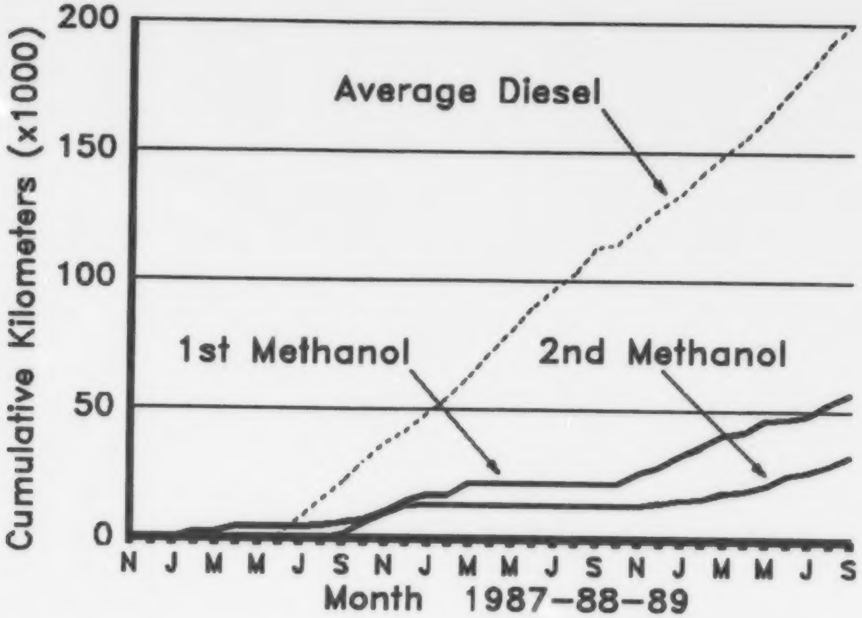

Figure IV-16. Cumulative Kilometers: Medicine Hat Buses

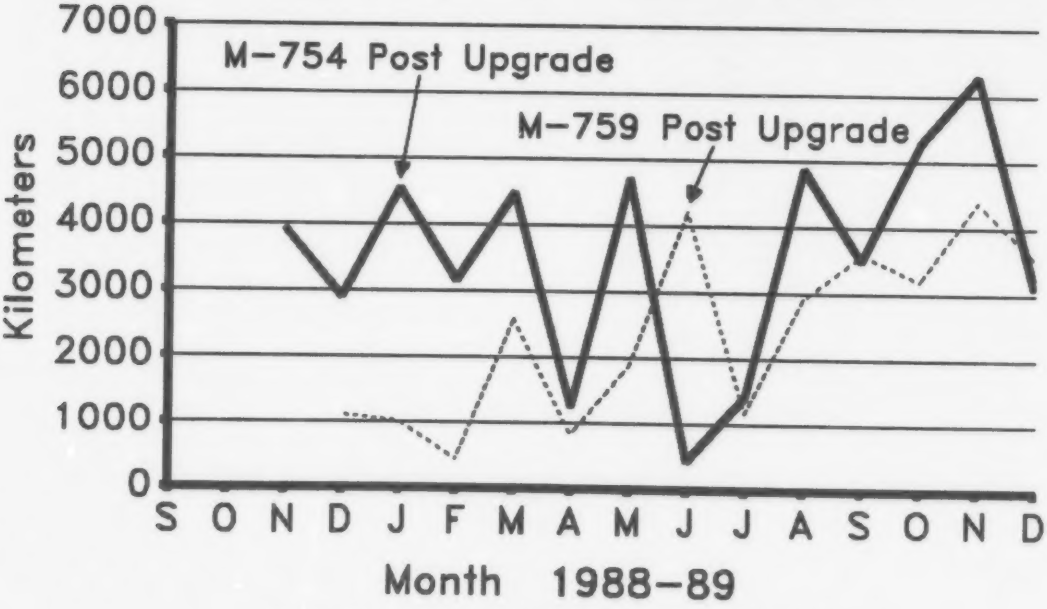

Figure IV-17. Monthly Kilometers: Medicine Hat Buses

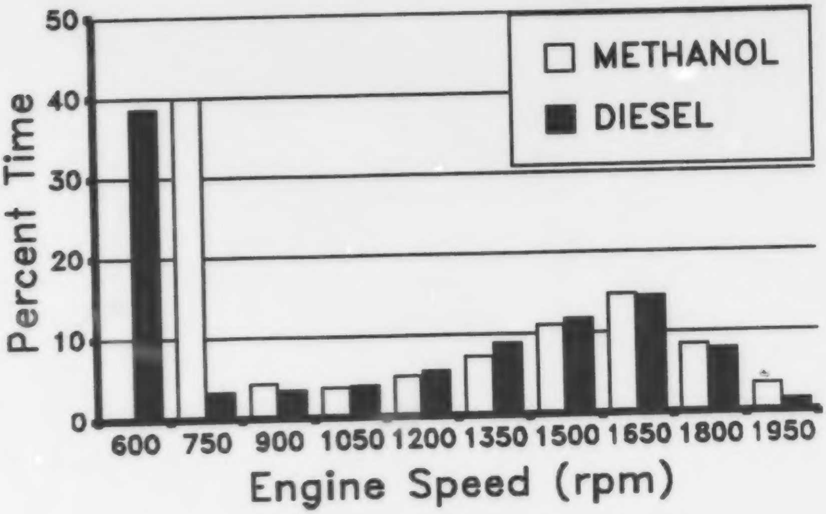

Figure IV-18. Engine Speed Profile: Medicine Hat Buses

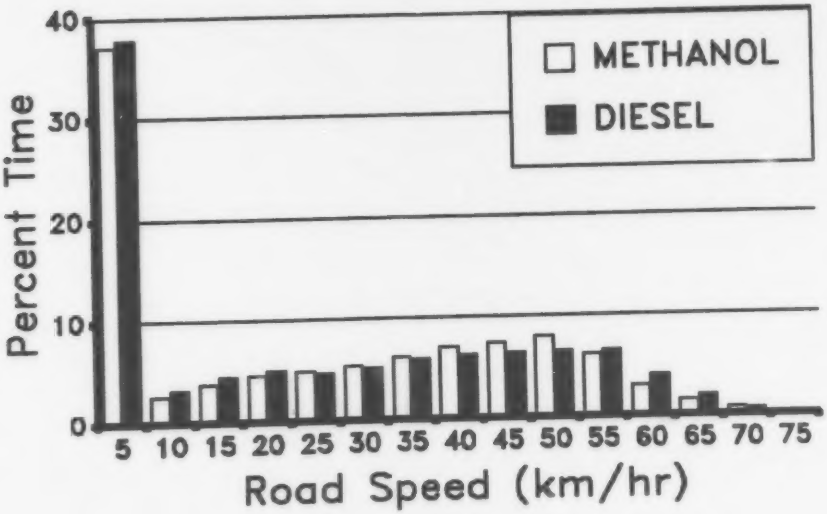

Figure IV-19. Road Speed Profile: Medicine Hat Buses

B.2. Vehicle Operating Profile

Histograms of the engine speed and road speed patterns for methanol and diesel buses typical of Medicine Hat Transit operations are shown in Figures IV-18 and IV-19.

The patterns show the typical high percentage of idling time, approximately 35% to 40% of total operating time. This is considerably less than the idling time at Winnipeg, and reflects the lower density of traffic in a much smaller city. Figure IV-19 also shows approximately 43% of total time above the 30km/h mark, against 22% for Winnipeg. Figure IV-18 confirms this situation in the engine rpm traces, showing approximately 39% of operating time above 1500 rpm for Medicine Hat, against 14% for the Winnipeg engines. Generally speaking the Medicine Hat buses operated at higher speeds and engine rpm levels, and they were also used on long and steep hills, which had no equivalent in Winnipeg. Figures IV-18 and IV-19 confirm that the project goal of similarity of operation between methanol and diesel vehicles was met, showing close similarity between the road speed and engine speed profiles for each type, except for the characteristic higher idle speed range for the methanol engines.

B.3 Fuel Consumption

The operational history of the Medicine Hat Transit methanol buses was very inconsistent prior to the engine upgrading work performed in September 1988. Only data gathered since September 1988 is presented in this report. Table IV-8 shows a summary of the fuel consumption of the methanol and control buses for the months October 1988 to September 1989.

At Medicine Hat the fleet was small and buses did not get placed in a common use pool in the same way as they did in larger fleets such as Winnipeg Transit. Generally a bus was used on the same route with the same drivers for several weeks. This led to individual trends in fuel consumption according to the habits of the drivers and the nature of the route. There were some routes incorporating long steep hills, and some which had very few gradients. Figure IV-20 shows the variations in monthly fuel consumption for the period under examination. The variation in consumption between the two methanol buses, 754 and 759, is 15% of the lower figure, and is also accounted for by the ongoing repairs to, and refinement of the engines which continued into 1989.

When considering the comparison between overall methanol consumption and overall diesel consumption it must be borne in mind that the methanol engines were set to give 277bhp when the upgrade work was completed. The control diesels continued with a rating of 200 bhp @ 2100rpm. The drivers of the methanol buses made full use of the extra power and torque available, and this reflected in the fuel consumption comparison figure.

B.4 Driveability

Because of the poor performance levels experienced until the Summer of 1989, a decision was made not to survey the drivers formally for driveability data.

From conversations with the management, maintenance staff and drivers themselves, it was found that the buses were generally no different to operate than the remainder of the transit fleet, when the engines were performing properly. The rough engine idle, especially when starting from cold, was an unpopular feature in the early stages of the project. This was cured by subsequent engine modifications. As at Winnipeg, the increased power available after September 1988 made the buses much more acceptable to the drivers.

Table IV-8. Fuel Consumption: Medicine Hat Buses

Bus No.	754	759	757	758
Distance Travelled (km)	36545	19796	91508	83117
Fuel used (litre)	52912	32808	48142	48040
Litres/100km	144.79	165.73	52.61	57.8
Methanol Average Litres/100km				152.14
Diesel Average Litres/100km				55.08
Methanol to Diesel Consumption Ratio 2.76 to 1.				

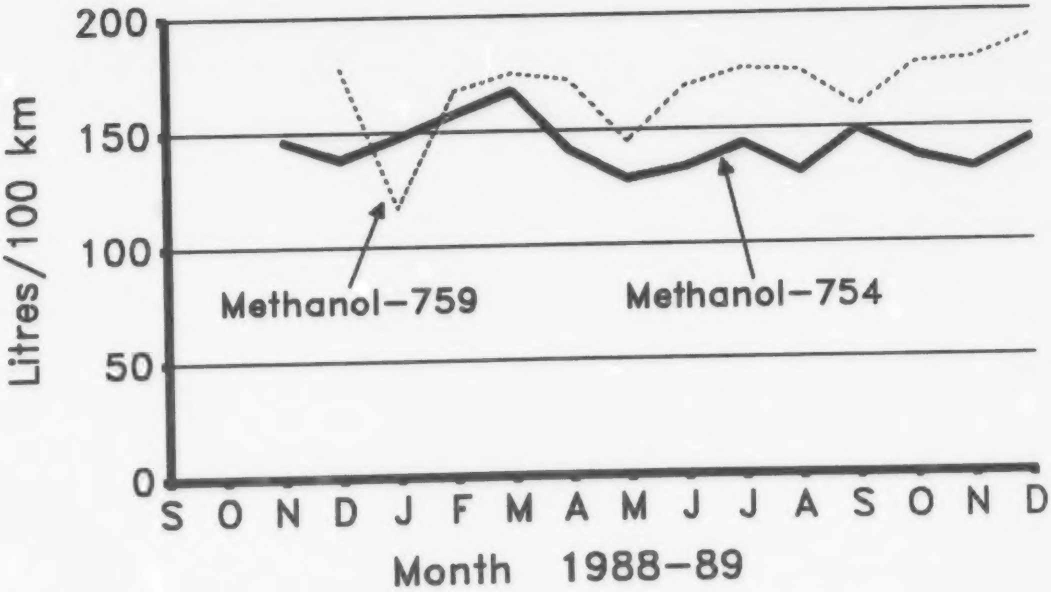

Figure IV-20. Monthly Fuel Consumption: Medicine Hat Buses

B.5 Fleet Attitudes

The largest methanol production plant in Canada is located in Medicine Hat. This was the major motivation behind the city's initial interest in project MILE. The fleet is a small closely-knit organization, operating 9 buses at any given time to service 6 routes on a 6 day per week basis. The project began with a high level of interest, and the inauguration of the first methanol bus, 754, was a major public event attended by the mayor, alderman and ministers from both federal and provincial governments.

At the outset of the project, one mechanic was assigned to diagnose and repair the methanol buses. This did not, as time progressed, prove to be totally beneficial. If this person was absent from the facility due to vacation or other reasons, there was no other experienced maintenance person to remedy problems. In the Summer of 1989 Detroit Diesel Corporation presented a training seminar to all four maintenance employees, so that breakdowns would not have to wait for the availability of one person. In the interim the local Detroit Diesel dealer was occasionally used to assist in dealing with non-methanol-specific items.

As opposed to Winnipeg Transit, which refueled buses indoors, Medicine Hat had always fueled outdoors. Fueling the methanol buses outdoors did not present a problem. The only difference was ensuring that the grounding strap was connected to the buses during refueling, a minor departure from refueling the diesel coaches. However, fuel capacity was a problem. The Flyer coach body construction at Winnipeg allowed for the installation of a second tank. Winnipeg's buses could remain on the streets in service for a full day (nominally 18 hours). The construction of the Medicine Hat buses did not lend itself to installation of a second tank. Therefore, range was effectively cut in half.

Consequently, the Medicine Hat buses required at least one extra refueling per day in a normal tour of duty. This required the bus to be taken out of service around 11:30 a.m. traded off with a diesel bus, returned to the Transit facility for refueling, and then returned to a trade-off point to resume service. The methanol buses could not be used on Saturdays because no staff were available to carry out this interim fuelling operation. A number of locations for extra fuel tankage were investigated but the original coach manufacturer would not approve any such major changes to the stressing of the body structure.

The attitude of the fleet naturally turned to disillusionment during the long periods of downtime experienced in 1987 and 1988. There was a great degree of frustration over the universal lack of experience in diagnosing and repairing faults, and the non-availability of spare parts. Medicine Hat was also conscious of its isolated position in the project, remote from factory, dealer and SMI support. Visits from SMI staff were only partially successful in maintaining interest in the project when it was not possible to keep the vehicles consistently on the road. The fleet obtained provincial agreement to retain extra spare buses in order to cover for the methanol downtime, which contained the operational problems within bounds.

Despite the numerous setbacks Medicine Hat remained willing to continue with the demonstration. The renewed commitment by DDC in 1988, coupled with high levels of factory support, adequate on-site spare parts stocks and an awareness of the growing numbers of methanol buses operating in the USA, encouraged fleet management to specify methanol engines for three replacement buses which were delivered in December 1989. These were the first three methanol buses built in Canada on a production line basis. Subsequently, the decision was taken to order three more methanol buses for delivery in 1990. The methanol engines in buses 754 and 759 were modified to the same specification as the new buses in May 1990.

Figure IV-21. Williams Methanol Truck No. I-272

C. WILLIAMS MOVING & STORAGE KENWORTH/CATERPILLAR TRUCKS

C.1 Cumulative Distance Covered

Figure IV-22 illustrates the cumulative distances covered by the methanol and control trucks during the period February 1988 to June 1989, when all four vehicles were in operation. For ease of comparison all readings are normalized to zero at March 1st, 1989.

The methanol trucks, 272 and 289, recorded 262,000 km and 244,000 km respectively during the period under review, and the diesels, 203 and 205 likewise recorded 273,000 km and 305,000 km.

Since the proportion of mileage in non-revenue service was essentially negligible , these figures may be used as a good measure of the availability of the methanol trucks in comparison to the diesels.

$$\text{Availability (\%)} = \frac{\text{Total Methanol Kms}}{\text{Total Diesel Kms}} \times 100$$

$$= \frac{506{,}000}{578{,}000} \times 100$$

$$= 88\%$$

The eventual total distance covered by the methanol truck 272 during the project was 327,027 kms, and by truck 289 was 272,171 kms.

C.2 Vehicle Operating Profile

The Williams Moving fleet test was unique in the project, in that the vehicles were used on one fixed route, loaded to the same weights within close limits, and operated to consistent time schedules. This ensured a close match between diesel and methanol operating profiles, and it was immediately obvious if any major deviations occurred because the journey time and average speed varied. The nature of the route was also a complete reversal of the situation in the other 3 fleets, being predominantly highway driving at high average speeds with the engine operating in the higher power and rpm ranges for long periods of time.

Figures IV-23 and IV-24 are typical comparative engine rpm and ground speed histograms obtained from the methanol and diesel trucks.

The engine rpm profile (Fig IV-23) shows the higher idle speed setting typical of all makes of methanol engine in the project. In the case of the Caterpillar engine the principle reason for the higher idle speed was to obtain sufficient electrical power from the glow plug alternator under idling conditions. Glow plug power demand was highest at idle. A simple change of crankshaft/alternator drive ratios would have resulted in an overspeed condition for the alternator at high engine rpm. The danger was especially acute because the engines were fitted with the Caterpillar hydraulic engine braking option which permits up to 2,200 rpm under braking conditions. The simplest solution was to set the idle for the methanol engines approximately 150 rpm higher than the diesel setting (750 rpm vs. 600 rpm). The alternative of a custom-built alternator with a larger total capacity or augmented output at low rpm would have involved considerable extra cost and complication. The higher rpm setting also imposed a slight fuel economy handicap upon the methanol engines. However, the percentage of total time spent at idle speed was small so that in this application the increased fuel use was not critical.

At the other end of the rpm range the chart shows excellent overall driving practise, with negligible use of engine speeds in excess of 1,800 rpm, and between 70% and 80% of the time for both methanol and diesel engines in the 1,400 rpm to 1,800 rpm bracket, where the best fuel consumption was obtained, and engine wear and tear were minimized.

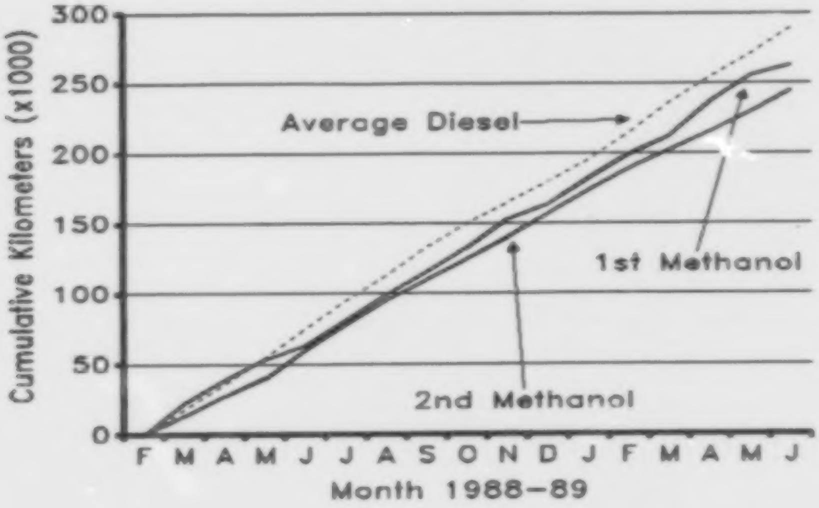

Figure IV-22. Cumulative Kilometers: Williams Trucks

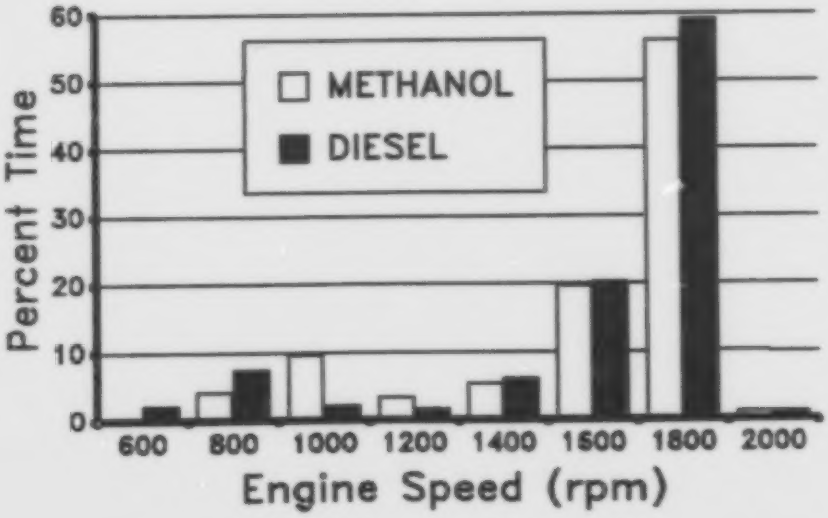

Figure IV-23. Engine Speed Profile: Williams Trucks

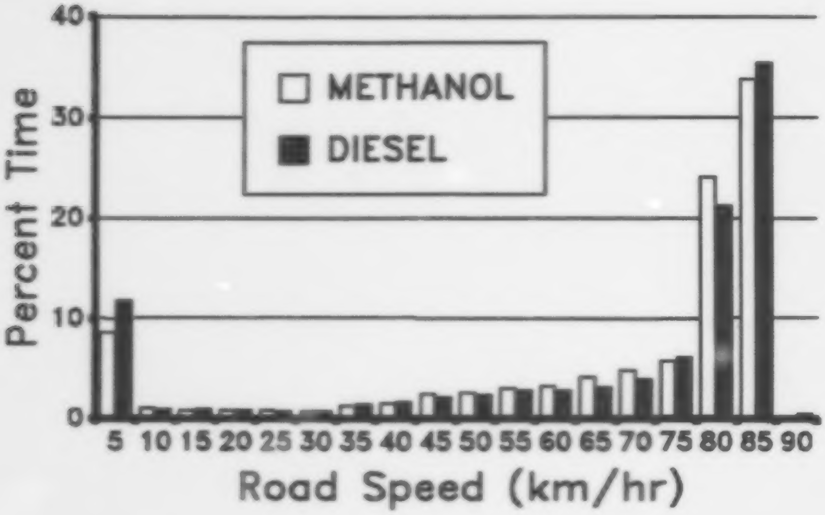

Figure IV-24. Road Speed Profile: Williams Trucks

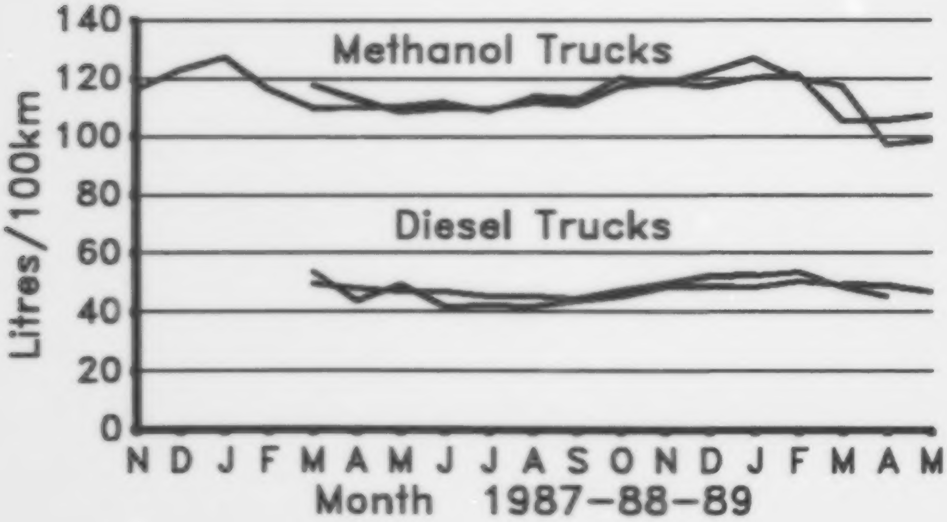

Figure IV-25. Monthly Fuel Consumption: Williams Trucks

Figure IV-24 shows the correspondence of vehicle road speed to engine rpm, with a 50% to 60% of total journey time in the 75 to 85 km/h range. The engines operated under good conditions of steady loads and temperatures. Williams Moving and Storage had already used trip monitoring devices for some years to encourage good driving, and the effect of this, plus the generally predictable nature of the route throughout most of the year, produced consistently similar driving profiles for the methanol and diesel trucks.

C.3 Fuel Consumption

The total overall fuel consumption figures achieved by the four trucks are shown in Table IV-9.

Figure IV-25 shows seasonal fuel consumption for the project trucks. As expected there was a tendency for consumption to increase during the winter months. The maximum winter consumption was 123 litre/100km, and the minimum summer figure 107 litre/100km for the methanol trucks. This represents a variation in fuel consumption of 15% of the minimum summer figures.

The corresponding plots for the diesel trucks, 203 and 205, show for 203 a maximum of 50 litre/100km and a minimum of 44 litire/100km, and for 205 48 litre/100km and 42 litre/100km. The variations of maximum to minimum here are 13.6% and 14.3% on the minimum figure.

The trucks were employed on a duty cycle which involved a very small proportion of starting and warm-up time and a large proportion of operation at relatively high speeds and high power requirements. The engines spend most of their operating time at full working temperature, and under these conditions the methanol engines exhibited similar seasonal variation in fuel consumption to the diesel engines. It seems entirely reasonable to assume that the variation in consumption which occurred was attributable to the same factors affecting the diesels, i.e. traffic delays, wheel slip, increased transmission and axle drag etc., rather than any inherent feature of the methanol engines.

The overall volumetric consumption ratio (methanol to diesel) of 2.4.1 is above the equal energy consumption range of 2.2 and 2.3.1. During engine development work Caterpillar had achieved equal energy consumption on a test dynamometer. However, when installed in a vehicle the engines were subjected to three handicaps absorbing extra fuel in comparison to the diesels. The weight of the extra fuel tank and fuel on average amounted to around 500 kg, which is 1.5% of a typical gross weight of 30,000 kg. The extra engine mounted alternator required to power the glow plugs, absorbed approximately 1,200 W depending upon engine operating conditions, equivalent to about 2 hp allowing for alternator losses. The methanol engine idle speed was 150 rpm higher than that of the diesel engines.

The fuel consumption of the methanol engines was influenced by the condition of the glow plugs and the fuel injector nozzles. However, the figures for both methanol and diesel were in a narrow enough band to make it difficult to meaningfully analyze the effects of engine condition against other critical variables such as driver habits, traffic conditions and load carried.

Generally the methanol consumption rate compared very well to diesel performance given the handicaps mentioned above, and the fact that no fuel economy optimization development work was attempted during the project.

Table IV-9. Overall Fuel Consumption Caterpillar Trucks

Truck No.	Fuel	Litres	KMS	L/100kms
203	Diesel	129,982	268,982	48.12
205	Diesel	144,680	313,775	46.11
272	Methanol	369,943	324,255	114.09
289	Methanol	291,322	260,121	111.99

The resultant overall volumetric fuel consumption ratio (methanol/diesel) was 2.406 to 1.

C.4 Dynamometer Testing

Figures IV-26 to IV-29 illustrate some results obtained during chassis dynamometer testing of the Caterpillar trucks, methanol and diesel. Figure IV-26 shows tractive power available at the rear wheels over the entire engine operating range. The diesel power curve was fairly flat, varying from 190 kw at 1,200 rpm to 210 kw at 1,800 rpm. The methanol curve was more humped, and achieved higher peak values, reaching 220 KW at 1,600 rpm. The plot of torque given in figure IV-27 showed close comparability in the 1,500 rpm to 2,100 rpm engine speed range, but the methanol engines had torque peaks in the 1,100 rpm to 1,200 rpm range 5% to 6% above that of the diesel unit. These graphs show that the methanol engines closely duplicated the power and torque characteristics of the diesel units. No special attempt to was made to explore the potential for greater low speed torque and power inherent in the methanol fuelling, which was not smoke-limited at peak torque. Caterpillar took as production target to duplicate diesel power, torque and brake specific fuel consumption. Figure IV-28 shows the b.s.f.c. recorded during the same series of chassis dynamometer tests. The methanol curve has been adjusted by the theoretical ideal volumetric energy content ratio, 2.25 to 1. The diesel engine showed lower values across the speed range with a minimum figure of 0.313 litres/kwh at 1,600 rpm, while the best methanol figure was 0.321 litres/kwh at 1,650 rpm. Figure IV-29 shows the most noticeable variation in operating parameters between the methanol and diesel engines, which was the lower exhaust temperature of the methanol engines. Typically under various load/speed conditions the exhaust gas temperature immediately ahead of the turbocharger was 50°C to 80°C cooler than for the diesel engine.

C.5 Engine Oil Analysis

The project engines, both methanol and diesel, were lubricated throughout the test duration by a conventional straight grade heavy-duty diesel engine oil, SAE 30 in winter and SAE 40 in summer, CD/SF rating. As mentioned in the technical description section, the methanol engines used a separate synthetic oil supply for the fuel injection pump plungers. This worked on a metered total loss basis with the surplus draining into the engine crankcase.

No lubricating oil consumption figures are provided since consumption was negligible between changes for all four engines.

Oil and filters were changed at 15,000 km intervals, corresponding to approximately once per month in regular operations. The crankcase capacity of the methanol engines was the same as the diesels at 38 litres. Normal consumption of synthetic fuel pump oil was 1 litre between oil changes. No attempt was made to account for the effect of the synthetic oil draining into the main oil supply.

Figure IV-31 shows the iron content of lubricating oil samples for both the methanol and diesel engines.

The samples were drawn as the sump was drained at oil change time. It may be observed that both methanol engines exhibited highest levels of iron content when new, with a tendency to stabilize at a lower level, generally in the 5 to 12 ppm range. In contrast the diesel engines, which were not new, exhibited a constant trend, in the case of truck 203 in the 17 to 25 ppm band. For truck 205 the swing was much wider, from 2 to 31 ppm. Williams Moving and Storage had its own oil sampling program which typically returned iron content levels for mid-life 3406 diesels in the 10 to 35 ppm range. Williams' experience was that the iron content was a good indicator of how an engine was being driven, to the extent that it was almost possible to distinguish between drivers by the characteristic levels.

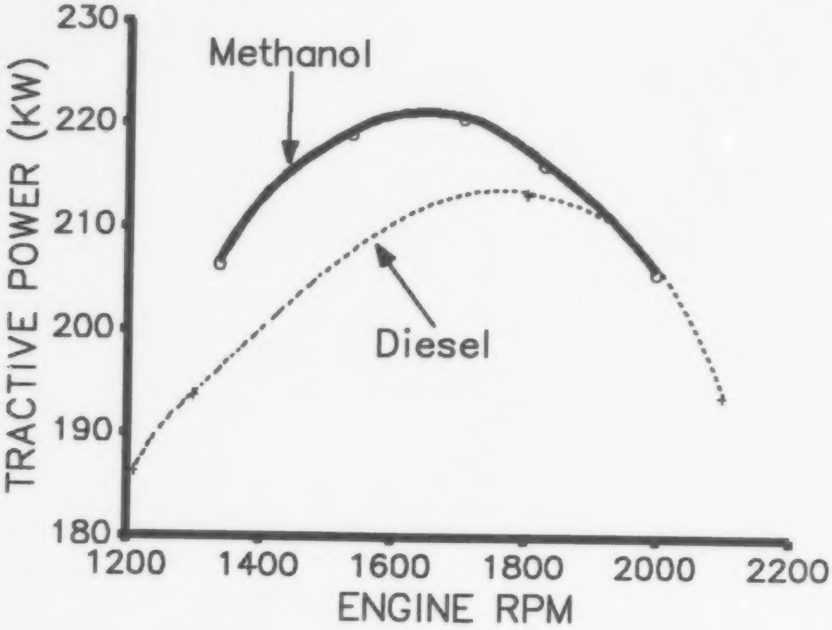

Figure IV-26. Dynamometer Tractive Power

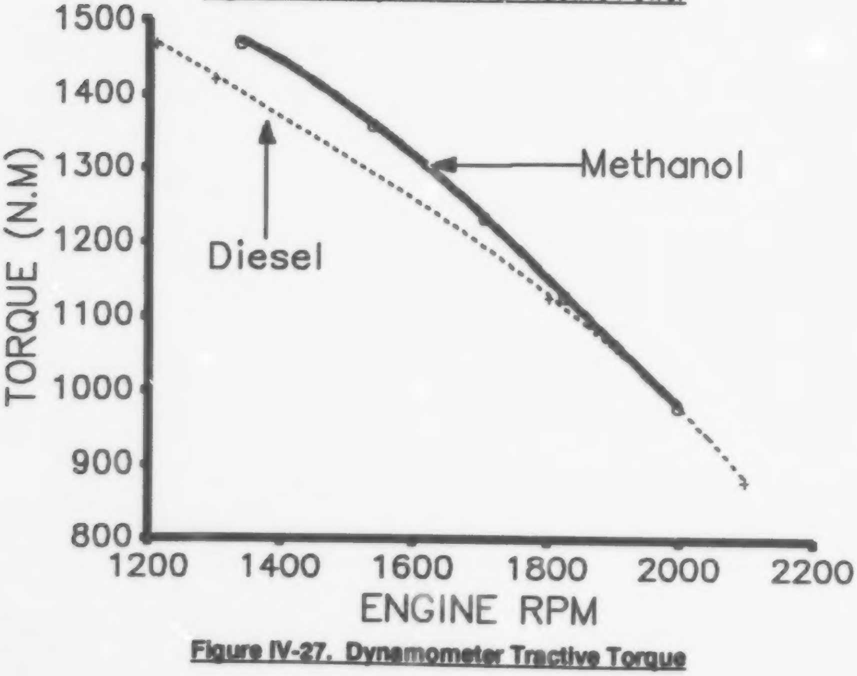

Figure IV-27. Dynamometer Tractive Torque

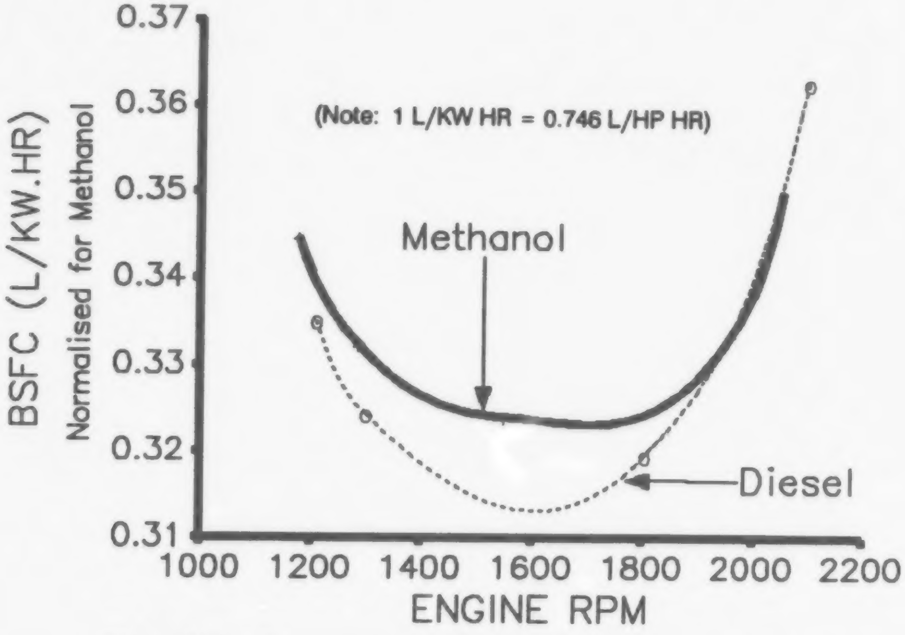

Figure IV-28. Dynamometer Brake Specific Fuel Consumption

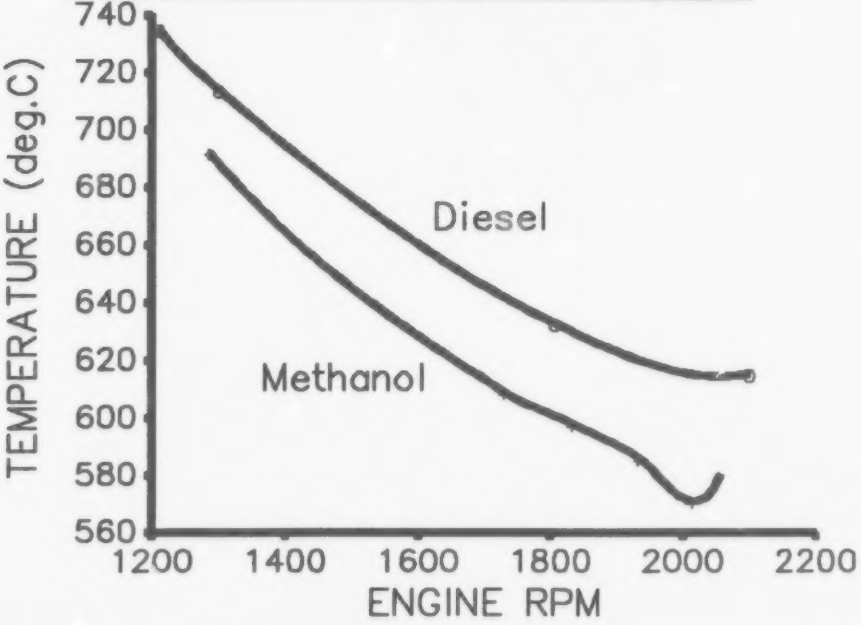

Figure IV-29. Exhaust Temperature

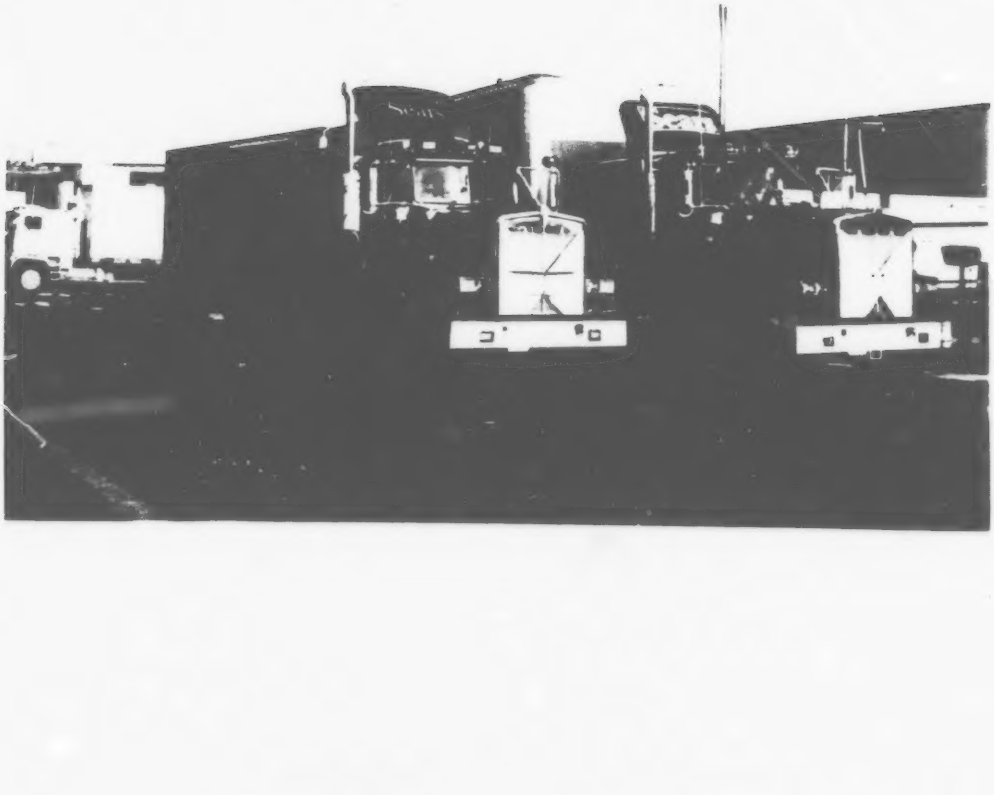

Figure IV-30. Williams Methanol (Right) and Diesel Trucks

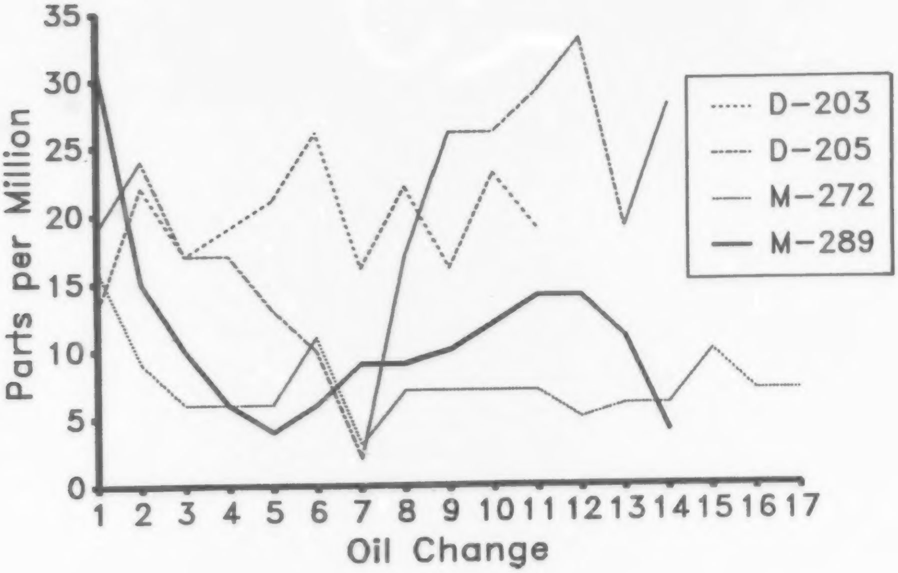

Figure IV-31. Iron Content of Engine Oil: Caterpillar

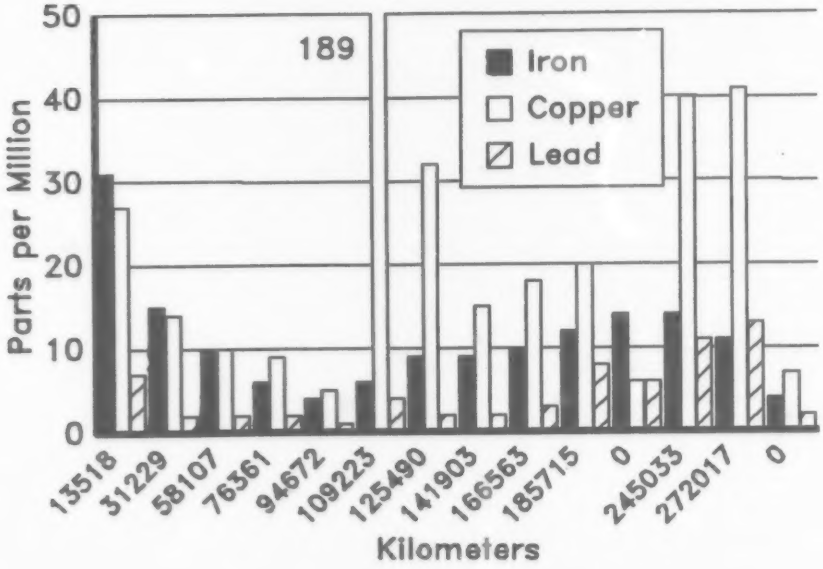

Figure IV-32. Methanol Engine Oil Analysis: Truck 289

The trend to lower iron content in the methanol engines continued throughout the project, and was taken as a indicator of a low wear rate on the cylinder liners, piston rings, and major rotating assemblies. Caterpillar Inc. had found similar results during some of its durability test work, and the subsequent engine dismantling and measurement work confirmed that the wear rate of the methanol units was no worse than that of a typical diesel of similar age.

Figure IV-32 illustrates the disposition of iron, copper and lead in the samples from methanol truck 289. The high copper readings were associated with internal coolant leaks due to head gasket failures experienced during the project. Figure IV-33 shows silicon content of the samples, generally taken as an indication of engine air filtration efficiency, and the total base number (TBN) of the oil.

Figures IV-34 and IV-35 report these results for truck 272, and Figures IV-36 to IV-39 apply to the two diesel trucks, 203 and 205. All of the engines showed occasional high copper levels as a result of internal coolant leaks, the copper originating in the radiator and/or oil cooler. The silicon content was an indication of the presence of abrasive in the oil and was usually in the 5 to 20 ppm range for the methanol engines, but remained mostly below 5 ppm in the case of the diesels. Occasional higher values were usually due to a leak past the engine air filter. There was no reason to suppose that the air filtration for the methanol trucks was consistently less efficient, since the filters were the same as for the diesel engines. The higher average silicon content does not appear to have resulted in higher wear rates in the methanol engines.

Lead originates in engine crankshaft bearings and can also enter the oil from internal coolant leaks, out of the solder in the radiator and oil cooler. Both diesel and methanol trucks returned lead levels generally below 5 ppm, with one instance of 33 ppm on 272, and two instances above 10 ppm for 289 (11 and 13 ppm). All of these comparatively high readings can be associated with internal coolant leaks, and the overall results suggest no real difference in bearing wear rate between the methanol and diesel engines.

The oil analysis service was not always able to provide Total Base Number for a sample, and the zero levels for TBN in the graphs indicate such lack of data. The TBN numbers for the methanol trucks showed no tendency to deteriorate to undesirably low levels, remaining in a similar 5 to 8 range as for the diesels. The engines were running consistently hot, at relatively high loads, and with frequent oil change periods. Under such conditions the TBN would not be expected to fall significantly below the original value.

C.6 Driveability

Driveability percentage scores for the methanol trucks are illustrated in Figures IV-40 and IV-43. The 50% level was intended to indicate an acceptable degree of operation, hence above 50% represented adequate to excellent results, and below 50% indicated a need for improvement or fault rectification. The engines were configured to give similar power and torque output to the 350 bhp version of the Caterpillar 3406 diesel, and this allowed them to be driven in the same way. These particular trucks were the only project vehicles using manual transmissions, and the drivers typically knew which gear they would expect to be using for a particular gradient, and the corresponding engine and road speed in a diesel truck. This enabled them to gauge the performance of the methanol engines more accurately, and to detect quickly whether an engine was losing power. The drivers were asked to rate their opinions for the diesel trucks for comparison, but the results obtained were of doubtful value, mostly being unanimous "good" ratings. The 3406 diesel is available in ratings up to 425 bhp for truck use, with a variety of custom torque curves. The methanol units could have matched this if required but Caterpillar selected the conservative 350 bhp figure for development work.

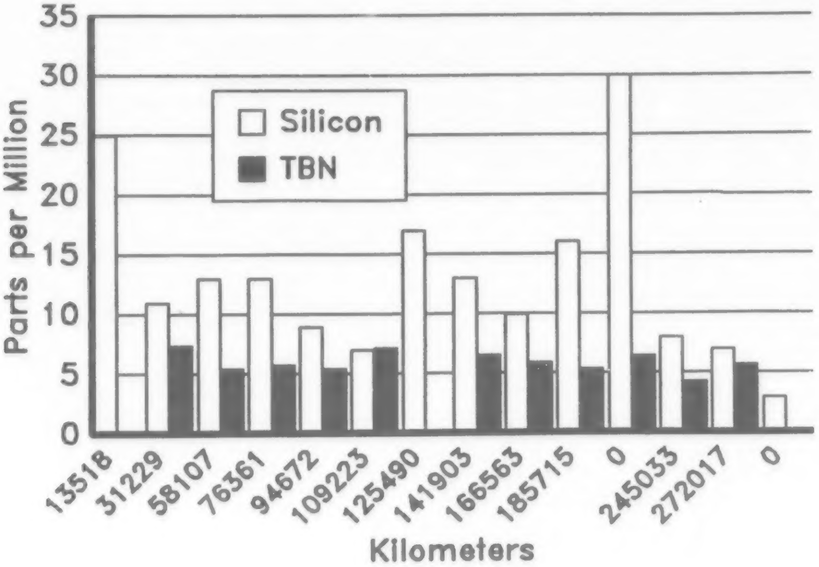

Figure IV-33. Methanol Engine Oil Analysis: Truck 289

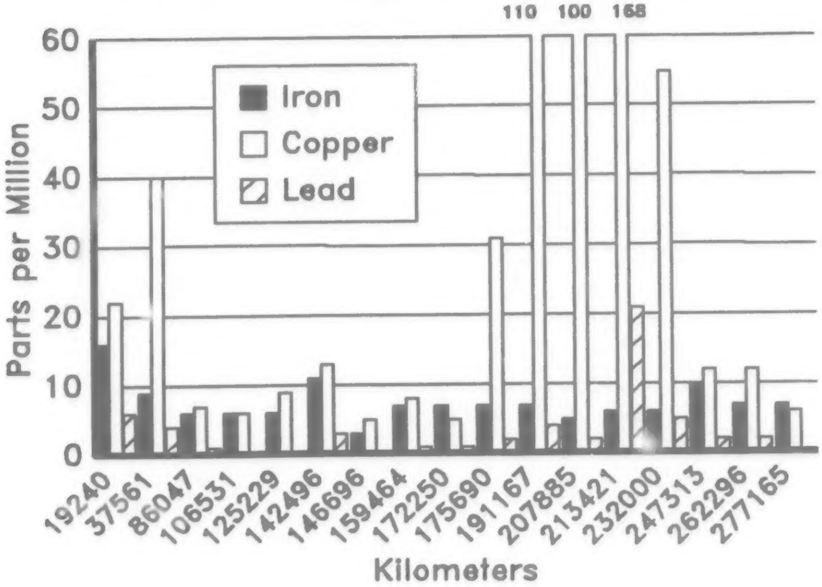

Figure IV-34. Methanol Engine Oil Analysis: Truck 272

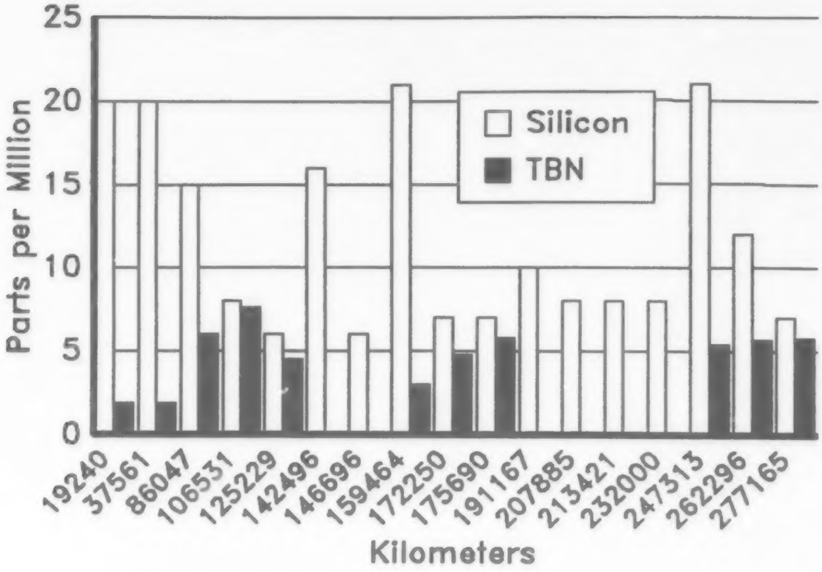

Figure IV-35. Methanol Engine Oil Analysis: Truck 272

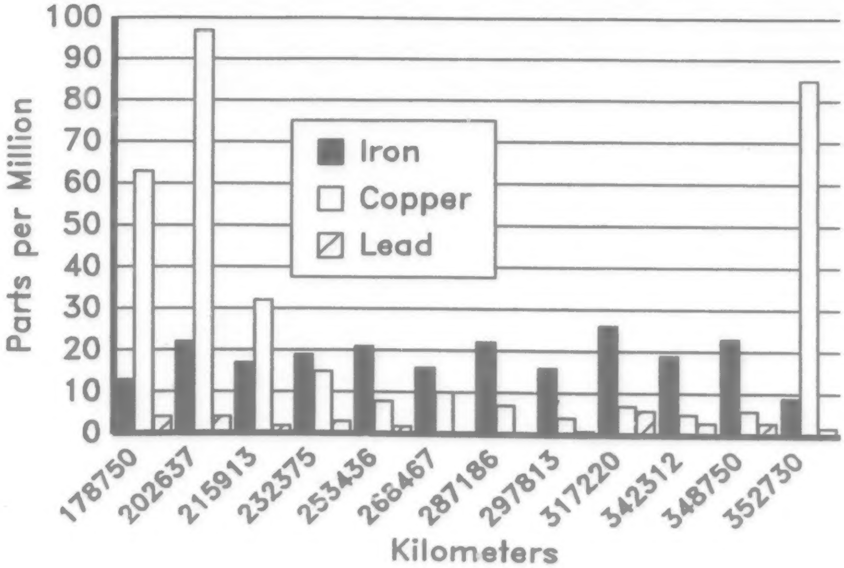

Figure IV-36. Diesel Engine Oil Analysis: Truck 203

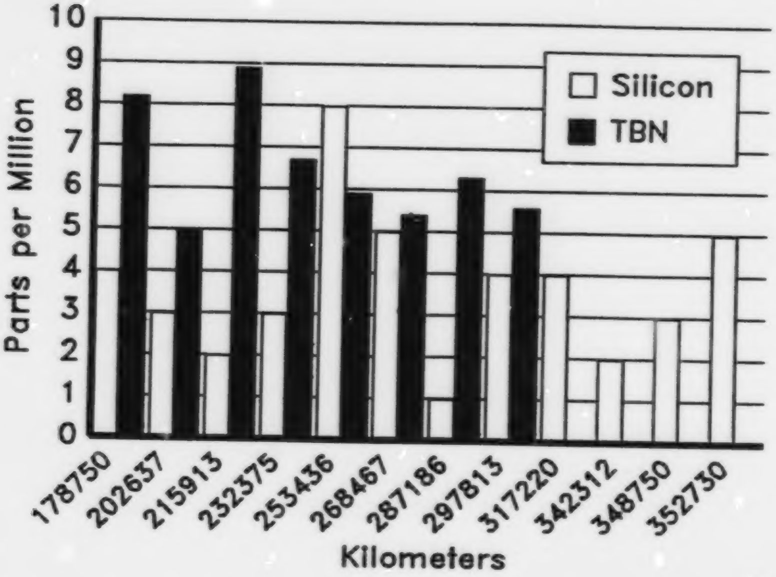

Figure IV-37. Diesel Engine Oil Analysis: Truck 203

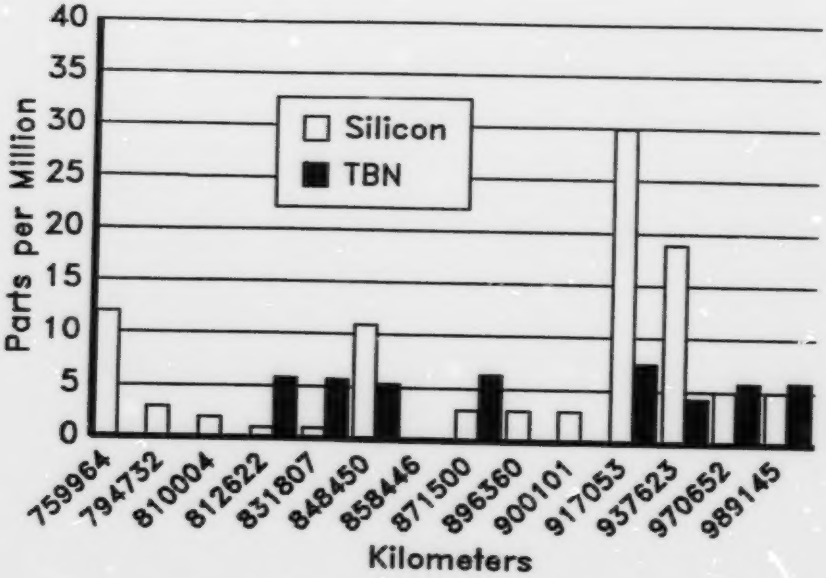

Figure IV-38. Diesel Engine Oil Analysis: Truck 205

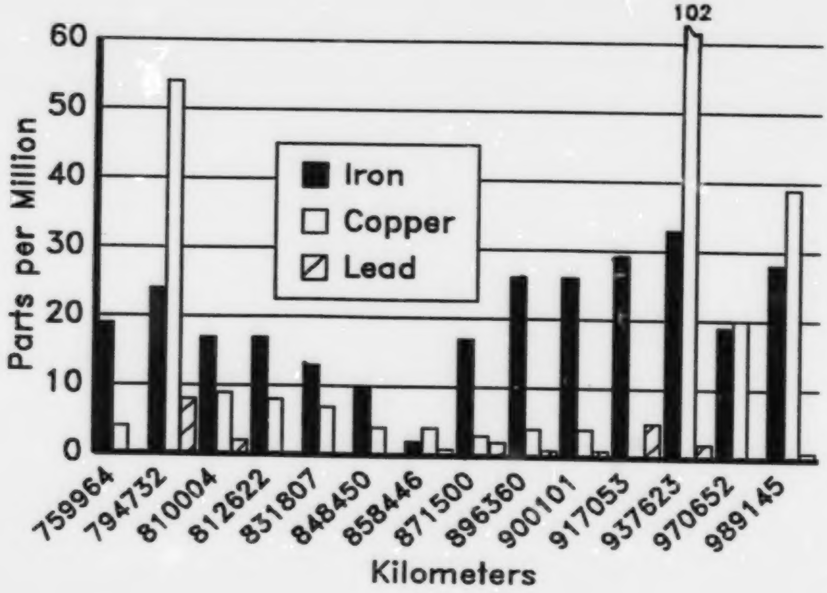

Figure IV-39. Diesel Engine Oil Analysis: Truck 205

Williams had in the past specified 400 bhp for the route used in the project, and the drivers were initially somewhat skeptical regarding the 50 bhp power loss, especially when the control vehicle diesel engines were downgraded to 350 bhp in order to maintain comparability with the methanol trucks. In addition, the drivers had to cope with the extra complication of the glow plug system, and the prospect of changing plugs on the road. This in fact was quite frequently needed in the early stages. Eventually Finning Inc., the Caterpillar dealer which undertook to maintain and repair the engines, devised a routine testing and replacement program to minimize the on-road glow-plug failure rate.

Hot and Cold Starts

Figure IV-40 gives the hot and cold starting scores for methanol truck 272. The most significant feature was the low ratings for cold starts in the early summer of 1988, reflecting a need for excessive cranking time before the engine would fire. This was traced to boiling of the fuel in the low pressure feed line from the fuel tank to the injection pump, and was cured by a modified pump feed side check valve. This maintained pump inlet pressure for a longer period of time between engine shutdowns, thus allowing quicker priming when the engine was restarted. This is also reflected in Figure IV-41, which shows a steady downturn in the engine idle quality due to the partial low speed fuel starvation caused by the boiling phenomenon.

Acceleration and Idling

The ratings for acceleration and engine idle quality are given in Figure IV-41. Few comments were received regarding idle quality during the project, and it rated a fairly consistent 50% score. The engines were normally quite smooth in operation with no misfiring, even when starting from cold. The higher idling speed of the methanol engines, which can affect ease of gear selection at rest, did not appear to worry the drivers. In any case a production engine would be configured to idle at a similar speed to a diesel.

The ratings for acceleration were less consistent. The drivers were particularly sensitive about the acceleration of the methanol trucks and this was one feature which was critically examined in comparison to the diesel units. Low scores were frequently associated with a need to attend to the glow plug system or change one or more fuel injection nozzles. Taken overall the drivers regarded the acceleration as acceptable.

On-Road Performance

Drivers were asked to rate on road operation above and below 50km/h, in order to differentiate to some extent high speed, high load conditions, and the part throttle light load situation which is often when a tendency to surge or "hunt" against the governor will occur.

The ratings are shown in Figure IV-42, and it is again apparent that the engines generally performed acceptably across the speed/load range. The most common speed range was 1400 rpm to 1800 rpm, and the engines pulled smoothly and evenly under light and heavy loading.

Shifting and Overall

Figure IV-43 shows ease of transmission shifting and overall impression for methanol truck 272.

The methanol trucks were normally rated at least satisfactory in both categories. The two Kenworths were the only project vehicles with manual transmissions, and the inclusion of comments on ease of shifting was intended to explore how the engines responded to the rapid changes of rpm and loading involved in making a ratio shift. If an engine is sluggish in gaining or losing rpm it becomes very difficult to make smooth easy changes, which is hard on driveline components and tiring for drivers.

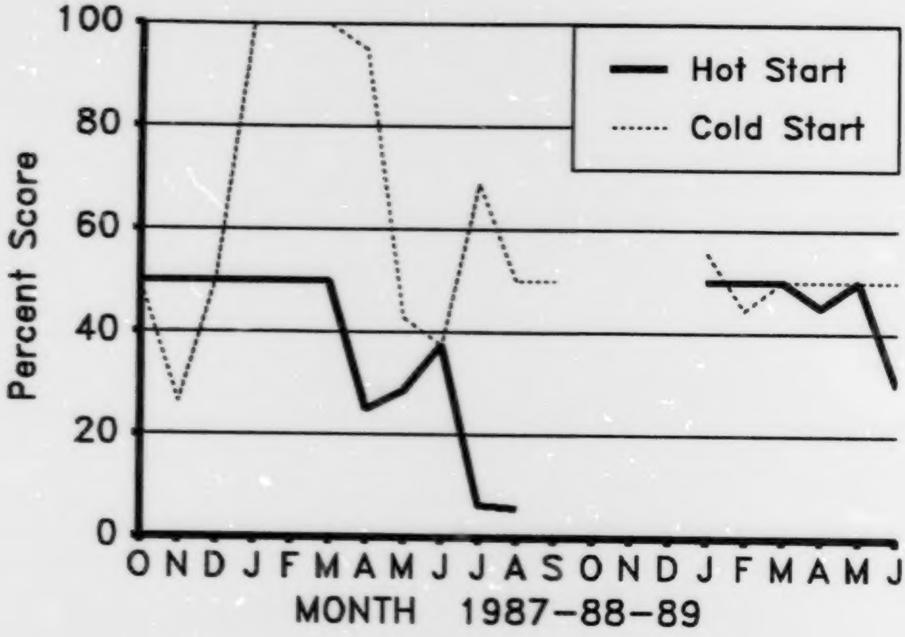

Figure IV-40. Driveability Rating: Hot and Cold Starting

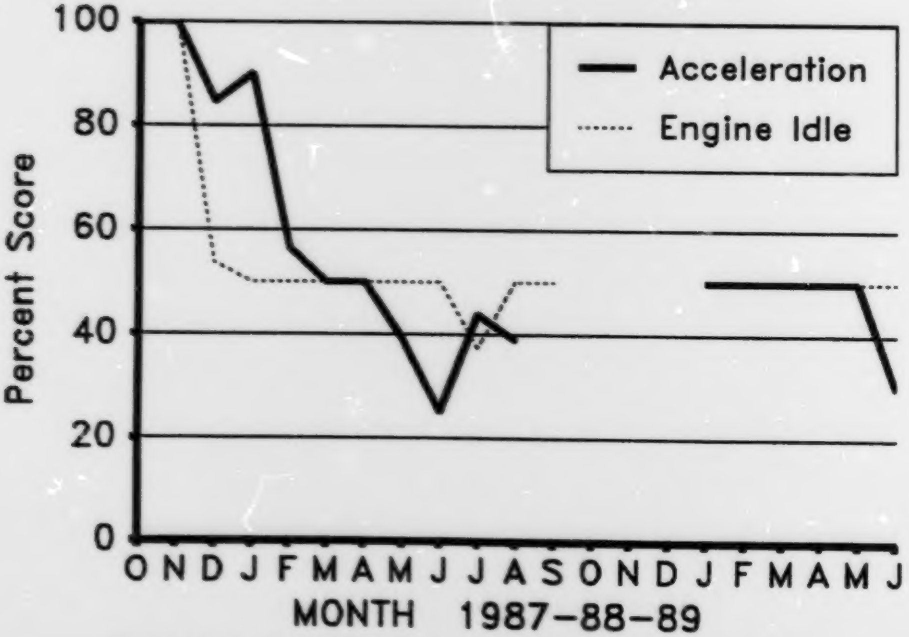

Figure IV-41. Driveability Rating: Acceleration and Engine Idle

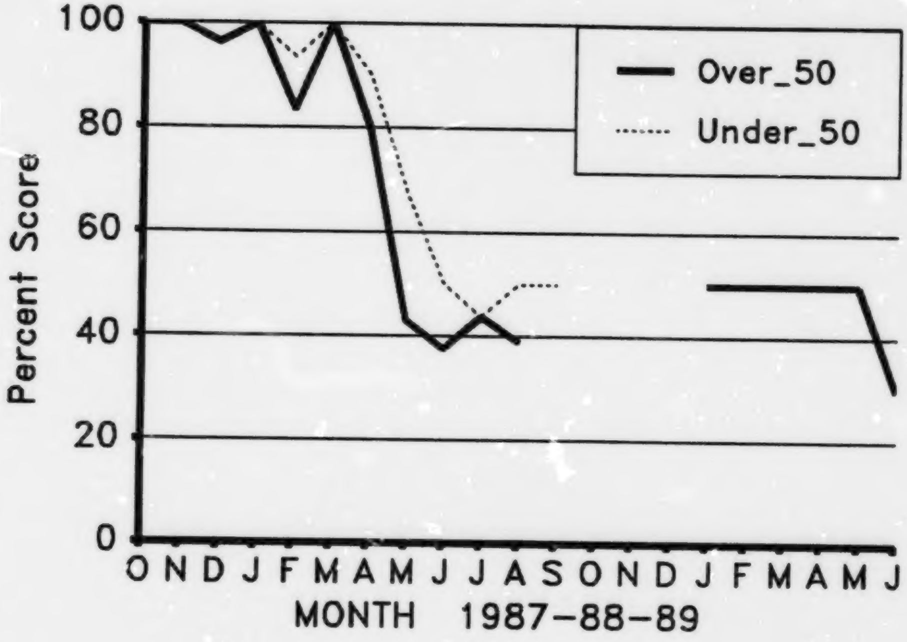

Figure IV-42. Driveability Rating: Over and Under 50km/hr.

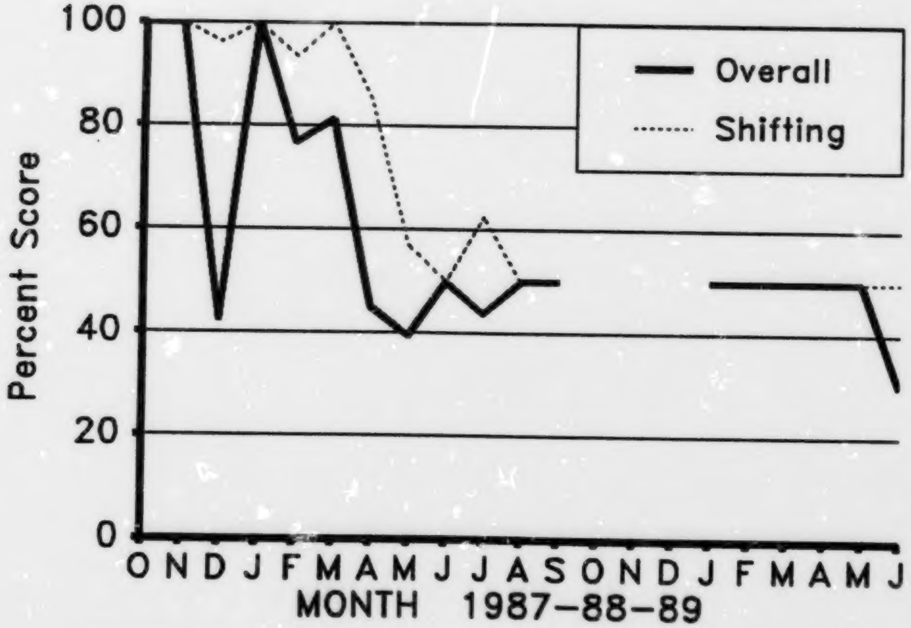

Figure IV-43. Driveability Rating: Transmission Shifting and Overall

There was no indication that the methanol engines had any shortcomings in this respect. The most obvious general trend in performance graphs is the change from high ratings early on to the "fair" or "satisfactory" level during the last 12 months of operations. There was no obvious technical reason for this, and no changes were made to the engines which would account for any power loss or other deterioration. The reason is probably largely psychological. At the start of the project the engines and the idea of methanol power were both quite new to the fleet, and all concerned were agreeably impressed when truck 272 went virtually straight into routine service and quickly demonstrated that it was well up to the demands of the job. As time passed the drivers became more critical and a few drawbacks, such as glow-plug reliability, were revealed. Eventually the methanol trucks were largely accepted as "normal", with nothing remarkable about them one way or the other. This is probably the best tribute which could be paid to vehicles in such a fleet demonstration situation.

C.7 Fleet Attitudes

Williams Moving and Storage Ltd was the only privately owned fleet participating in project MILE. The route assignment for the vehicles was about as much in contrast to the urban and suburban environments of the other project vehicles as it was possible to get. Each trip involved synchronization with other parties at the warehouse loading point and the trailer exchange near Canmore. In these circumstances breakdowns were very noticeable and extended out of service time could not be accepted. The owners of the company were surprised and impressed by the two methanol trucks, and encouraged to continue active exploration of alternative fuels by participating in future fleet tests.

The drivers were required to be particularly open minded about the trucks, since they were undertaking 1800 km round trips along highways remote from immediate assistance. Any engine failure could at a minimum result in a long wait for help, and at the worst could be very hazardous. In addition they had to be prepared to change glowplugs along the way and make extra refueling stops. Each truck was normally driven by a crew of 2 regular drivers, and counting the occasional substitutions about 8 drivers actually handled the methanol vehicles during the course of the project. There were periods of frustration, when hot starting became difficult and when power output declined prior to injector nozzle changes. There were also a number of problems with the fueling station at Sicamous which sometimes resulted in long waits to fill up with methanol. Drivers will often attempt to avoid unpopular vehicles, but there was no evidence that this was happening to the project trucks. It was concluded that the drivers were essentially happy with them.

Williams Moving and Storage was not interested in any immediate future extension of methanol use in its fleet. This conclusion was not unexpected, despite the excellent showing of the vehicles, and was based on a number of considerations, the three most prominent being higher fuel costs, very restricted availability of fuel, and higher maintenance demand and costs. Obviously, even if fuel and maintenance costs are reduced to competitive levels a long distance haulage fleet cannot contemplate using a fuel which is not readily available on a wide scale.

D. CITY OF VANCOUVER FREIGHTLINER/CUMMINS TRUCKS

D.1 Cumulative Distance Covered

Methanol truck 874 covered 20,752 km during the period June 1988 to September 1989. The second truck 875, covered 6,090 km from February 1989 to September 1989. Average monthly distances were 1,383 km and 870 km respectively. Figure IV-45 shows the graph of cumulative distance for the trucks during this time.

The curves for the two diesel control vehicles show the typical average monthly distance travelled to be approximately 2,600 km up to March, 1989, and 1,200 km thereafter. This reflects a significant change which occurred in the operational procedure for the City of Vancouver garbage collection service.

Generally it can be seen that the first methanol truck (874) kept pace with the diesels until September when it was out of service for attention to engine stalling and shut-down problems. By April 1989 it had recorded about 61% of the average cumulative kilometers of the two diesel control vehicles. During March and April 874 was undergoing repairs for bodywork damage, and in February the engine was dismantled for inspection proposes after 1000 hrs service. The time lost for these tasks represented about 3,000 kms on the road. If this lost distance is factored into the calculation then the methanol truck 874 would have achieved over 77% of the average diesel service kilometers during its first year of operation.

Prior to March 1989 the trucks would make their local round, and when filled travel directly to the city dumpsite about 30 kms away. In March a new compacting facility was opened at the maintenance yard, and the trucks returned to the yard to off-load. Special high-volume semi-trailers were used for the haul to the dumpsite. Distance travelled was a poor indicator of the severity of the duty cycle for these trucks, which spent a high proportion of their time running the power take-off during loading and compacting of garbage. Each truck worked one shift per day on weekdays only, usually of 10 hrs duration, and loaded around 70 containers of garbage in that time.

D.2 Vehicle Operating Profile

Figure IV-46 and IV-47 are the histograms of road speed and engine speed respectively for methanol and diesel trucks in Vancouver. The profiles are very like those for the transit buses included in the project, with an overwhelming percentage of operating time spent at a standstill with the engine at idling speed. The power-take-off drive was normally in use for much of the apparent "idle" time, to drive the self loading and compacting gear, but the project instrumentation was not able to distinguish when the power-take-off was in use. As for all the other methanol engines in the project the Cummins units idled approximately 100 rpm faster than the diesel engines, and this is shown in Figure IV-49, where the diesel idle time spans the 600 to 750 rpm range boundary, and the methanol is divided across the 750 to 900 rpm line. The other speed ranges showed very close correspondence between the two fuels.

Road speed showed essentially negligible operating time above 60 km/hr and a very close profile match for the methanol and diesel vehicles.

D.3 Fuel Consumption

The fuel consumption (litre/100km) for the City of Vancouver trucks appears to be very high in absolute terms for both methanol and diesel vehicles. This is a reflection of the particular nature of the duty cycle. In an attempt to better express the fuel use rate the trucks were fitted with hour meters to record daily operating hours. This method was not a success during the period under review, since the operating staff did not consistently recorded the meter readings and so any meaningful analysis was frustrated.

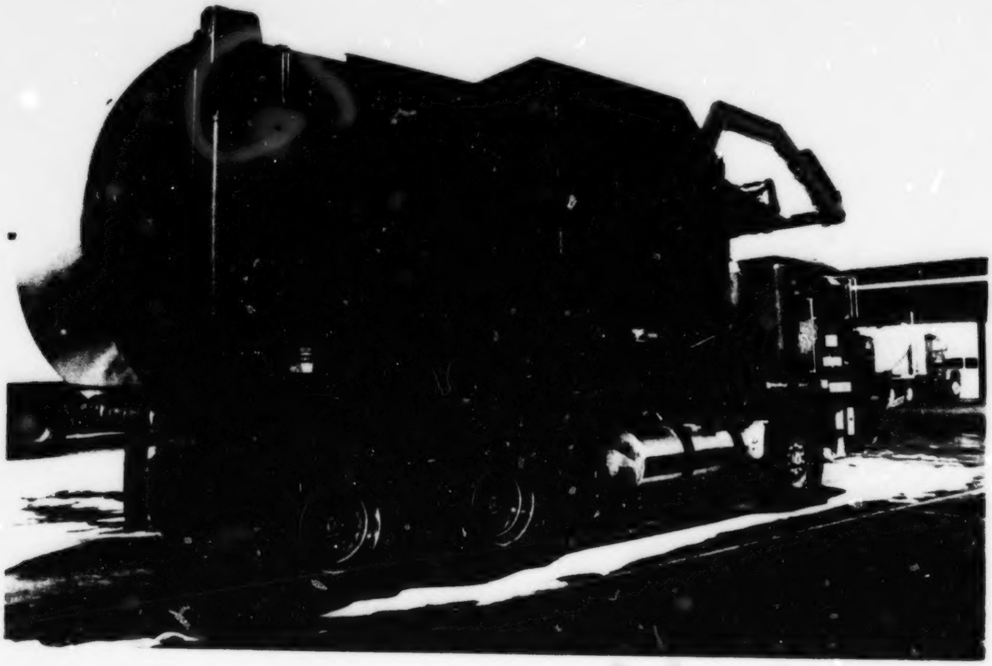

Figure IV-44. City of Vancouver Methanol Truck

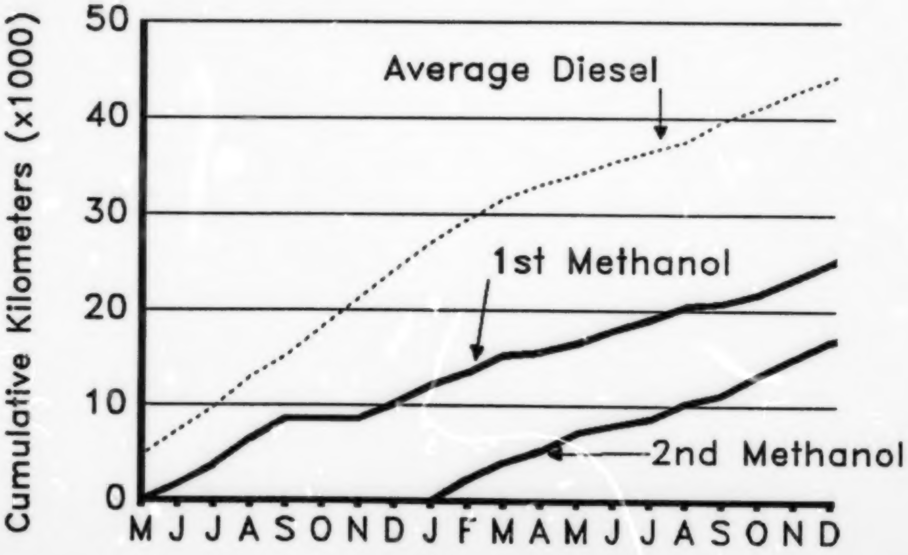

Figure IV-45. Cumulative Kilometers: City of Vancouver Trucks

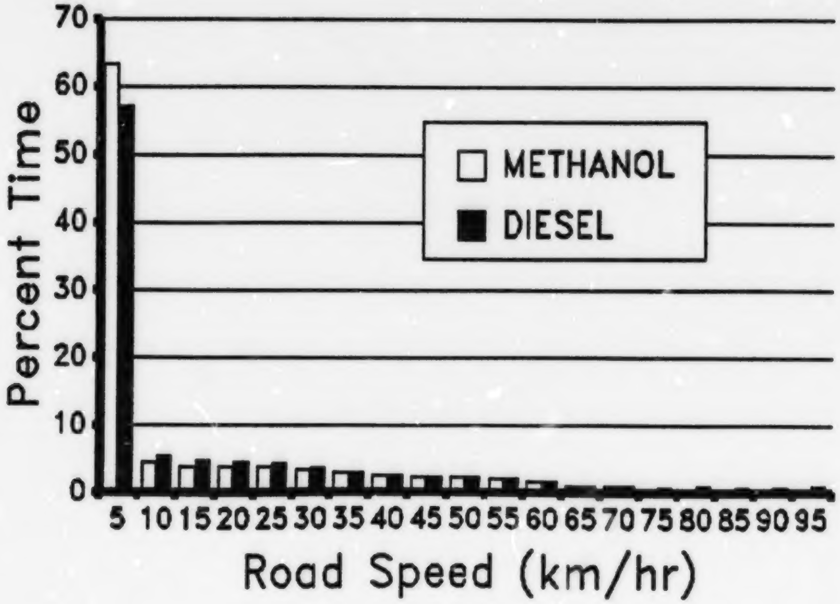

Figure IV-46. Road Speed Profile: City of Vancouver

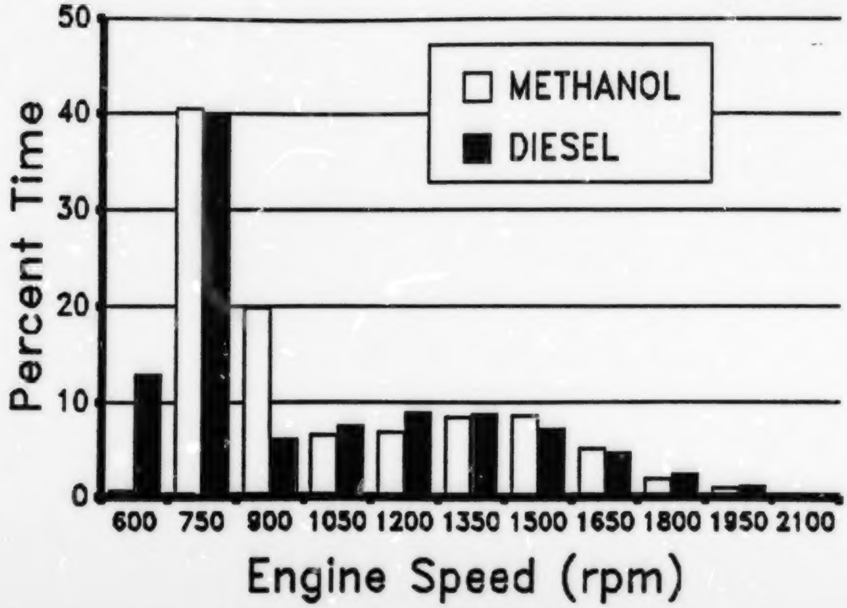

Figure IV-47. Engine Speed Profile: City of Vancouver

Table IV-10. Fuel Consumption: Cummins Trucks

Truck No.	Consumption (Litre/100km)	
	Before March 1989	After March 1989
M874	151.7	184.3
M875	-	184.8
D878	62.7	71.4
D879	70.0	88.9
Methanol Average	151.7	184.6
Diesel Average	66.3	79.4
Methanol/Diesel Ratio	2.29:1	2.32:1

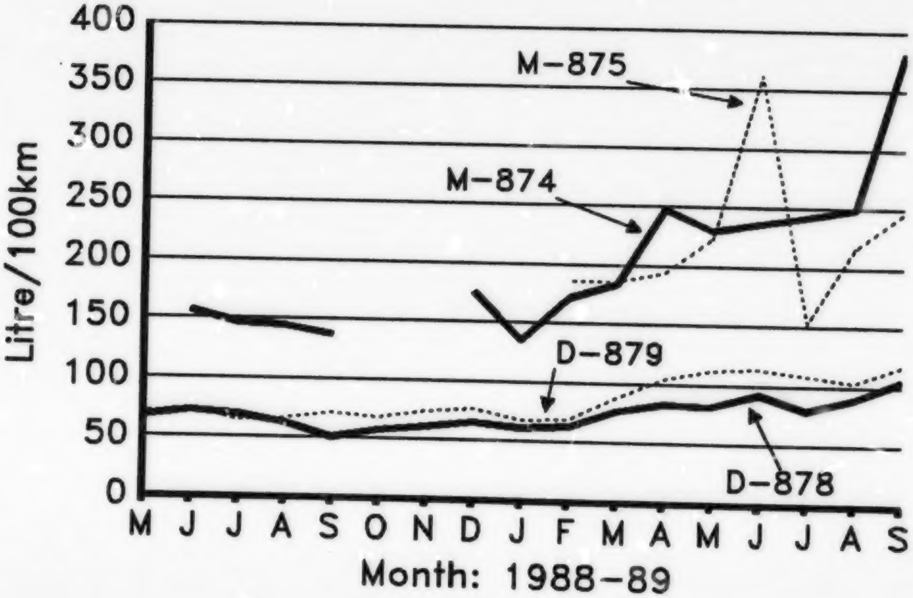

Figure IV-48. Monthly Fuel Consumption: City of Vancouver

The distances achieved by the trucks may be roughly translated into operating hours by using a factor of 10km per hr., giving 2200 hrs for truck 874 and 1000 hrs for truck 875. Although the actual absolute fuel consumption figures are specific to this particular mode of operation the comparison between methanol and diesel is valid, since both types of engine ran under the same conditions.

The fuel consumption history was essentially divided into two distinct periods, before and after March 1989, when the change to a centralized dumping point was made. Table IV-10 shows the fuel consumption figure for all four trucks. Methanol truck 875 did not operate for a significant period of time prior to March 1989.

The close correlation between the consumption figures for the two methanol trucks, 874, and 875, is interesting in view of the different power ratings of the engines. It is probably a reflection of the duty cycle which seldom, required sustained high power outputs after the freeway part of the route was eliminated.

Figure IV-48 gives the monthly fuel consumption for methanol trucks 874 and 875 throughout the project, and the comparative diesel results (878 and 879).

Figure IV-49 shows the first methanol truck, 874, to have achieved approximately 150 L/100 km at the start of the project, rising to the 200 to 250 l/100 km range after March 1989. The exceptionally high reading for 874 in September 1989 is not typical and results from a long period out of service and very low mileage during the month. A similar situation applied during June and July 1989 for truck 875.

Figure IV-48 also illustrates the corresponding rise in the fuel consumption for the diesel trucks after March 1989. 879 returned consistently higher fuel use than 878. There was no known mechanical reason for this, and it was therefore assumed to be due to variations in driving style.

Table IV-10 shows that the overall volumetric fuel consumption ratio of methanol versus diesel remained substantially constant before and after the change in operational procedure, in the 2.30 to 1 range. These results were obtained over approximately 65,000 kms diesel operations and 26,000 kms methanol operations. The figure of 2.30 to 1 is very close to the generally accepted equal energy consumption ratio of 2.25 to 1, and was the closest figure achieved by project MILE vehicles.

There are at least two reasons which may account for the fuel consumption ratio achieved. These trucks did not require any extra electrical equipment to power glow plugs, fuel pumps or cooler fans, creating a parasitic load on the engine. Secondly, the amount of extra fuel carried in relation to the diesel trucks (100 litres maximum) was negligible in respect to total weight, and would have had a minimal effect in slow speed operations with a very high proportion of stationary time.

D.4 Cold Starting

The trucks were parked and started outdoors. In the mild climate of Vancouver cold starting never presented any problems. The engines had no auxiliary starting devices and block heaters were not fitted. Tests carried out by Cummins had confirmed that starting with methanol/Avocet blend fuel was possible at temperatures down to -6^{O}F, with much lower concentrations of "Avocet" than the 5% used in the trucks. At 1% concentration a start was achieved in 10 sec at -6^{O}F, equal to normal diesel starting time at the same temperature. At 0.5% concentration a start was achieved after 22 sec cranking time. The engines were lubricated with the standard "universal" 15W-40 oil used throughout the City of Vancouver vehicle fleet, which would allow easier starting at near freezing temperatures than a straight grade oil.

It appears that the methanol/Avocet fuel blend will allow cold starting at least as easily as diesel fuel at any given temperature, and will also provide unassisted starts at temperatures below the normal range of diesel starting.

D.5 Engine Oil Analysis

The Cummins engines, methanol and diesel, were lubricated by a conventional multigrade 15W-40 "universal" oil, intended to be used in either gasoline or diesel engines. The mild climate of Vancouver allowed the use of the same oil throughout the year. At the start of the project Cummins asked that its own brand of lubricating oil be used but the fleet was unable to guarantee that no confusion between oil types would occur. It was concluded that the use of a nonspecialized type of oil would make the trials more representative of what an engine would experience in general fleet operations.

Table IV-11 shows the oil sample results for both methanol trucks (874 and 875) and one diesel truck (878).

Iron content, generally an indicator of cylinder bore wear, showed some scatter of results with a trend to higher levels at oil change for the methanol engines. The silicon content was included in the table as confirmation that the abrasive contamination of the oil was no different for both types of engine. Aluminium content (piston wear) and chromium (top rings) were generally closely comparable, although the methanol engines experienced peaks when all metal contents rose. The copper and lead peaks possibly originated from the oil cooler, as opposed to bearing wear, although their occurrence coincidentally with high levels of all metals, and low TBN numbers, indicates a time of generally excessive internal wear.

In February 1989 the first engine was dismantled after 1000 hrs in fleet service. General wear levels were well above normal for a diesel of comparable age. Extensive cracking was found in all six piston crowns. However the results of the inspection are not regarded as typical in view of the fact that this particular engine had been subjected to dynamometer testing prior to installation in the truck, including high power and overload work. The piston cracking was attributed to the greater cooling effect of methanol at point of injection, leading to wide cyclic swings of piston temperature. Cummins was well aware of this possibility and wished to explore the effect using variations of injector spray angle with standard diesel pistons as a first step. Modified piston designs were in preparation and later used in other trials.

More specialized lubricating oil may also help to reduce wear. The TBN rating tended to lower numbers for the methanol engines, indicating average higher levels of acidity in the oil. Unfortunately the oil analysis service used was not always able to provide TBN results so that any trend can not be confirmed.

At the conclusion of the period covered by this report (September 1989), the methanol engines were in regular service, and exhibited no external symptoms of excessive wear (eg. noise, oil smoke, blow-by etc.). The methanol engines used slightly less oil between changes than the diesels. Oil consumption rate (make-up oil) is shown in table 4-12.

D.6 Driveability

Table IV-13 shows driveability percentage scores obtained for methanol truck 874 on a monthly basis from June 1988 to June 1989.

Table IV-11 Oil Analysis Results Cummins Trucks

		Metal Content (ppm)							
Truck No.	Kms.	Fe	Al	Cr	Ni	Cu	Pb	Si	TBN
M-874	4726	58	2	2	1	125	28	9	8.3
	8960	19	1	0	3	44	26	5	7.0
	13067	25	5	1	3	17	23	5	–
	19482	23	3	1	2	114	27	9	7.0
M-875	5643	55	3	3	1	22	10	7	6.8
	11490	115	5	10	5	159	29	7	6.1
	21121	13	2	1	2	6	2	5	–
	29283	25	2	3	4	79	46	7	–
D-878	14345	81	5	7	5	110	21	7	7.2
	38040	23	2	1	3	3	23	7	7.7
	43669	17	1	1	0	3	8	5	6.8

Table IV-12. Engine Oil Consumption: Cummins Trucks

	Methanol		Diesel	
	874	875	878	879
kms/litre	1600	961	858	949

Table IV-14. Driveability Scores: City of Vancouver Methanol Truck

Month	Cold Start	Hot Start	Idle	Accin.	Under 50km/hr	Over 50km/hr
June	100.0	50.0	100.0	100.0	100.0	100.0
July	83.3	50.0	90.0	100.0	93.3	100.0
August	72.5	55.0	92.5	100.0	100.0	100.0
September	57.7	50.0	100.0	96.2	100.0	100.0
October	0.0	0.0	0.0	0.0	0.0	0.0
November	0.0	0.0	0.0	0.0	0.0	0.0
December	88.9	38.9	94.4	100.0	94.4	100.0
January	76.7	46.7	100.0	96.7	100.0	100.0
February	100.0	57.1	100.0	100.0	100.0	100.0
March	94.1	17.6	82.4	97.1	91.2	97.1
April	80.0	0.0	60.0	80.0	80.0	80.0
May	75.0	0.0	33.3	91.7	66.7	66.7
June	66.7	0.0	0.0	33.3	0.0	16.7

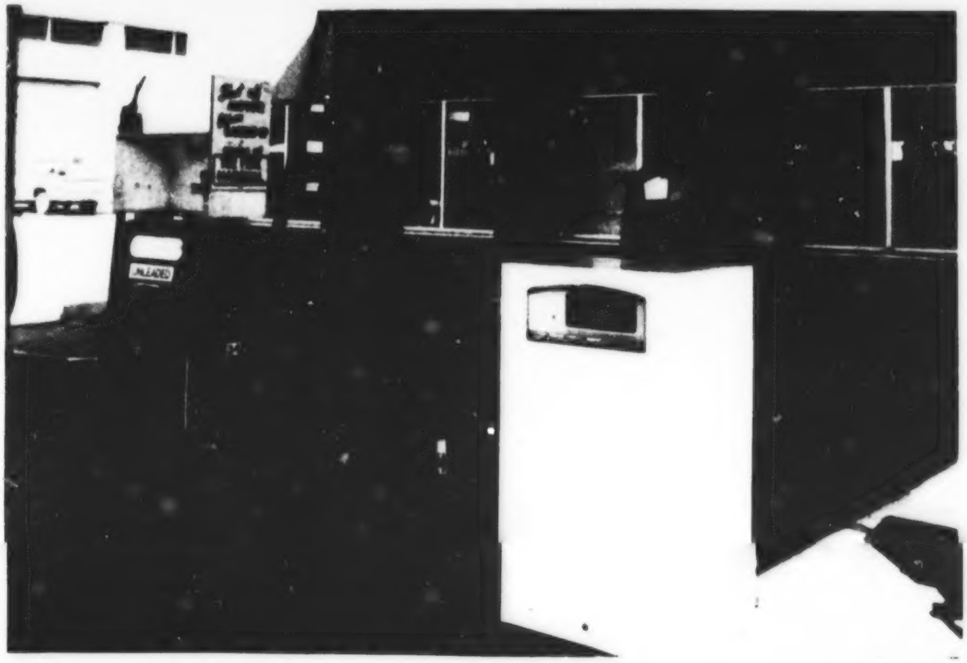

Figure IV-49. City of Vancouver Methanol Dispenser

In October and November 1988 no driveability reports were submitted as the truck was under repair. The general deterioration of scores during April, May and June 1989 was caused by tendency for the engine to stall at low speeds under load. This was associated with fuel vaporization at low fuel system pressures and high engine temperatures, and so became more acute in warm weather.

Hot starting as the weakest driveability characteristic, with acceleration and over 50 km/hr performance as the strongest points. Generally the methanol engines were at their best when under high loads.

A significant problem for this application emerged after the low speed stalling was cured by attention to the fuel pump and fuel line pressures. The engine rpm did not slow as quickly as for a diesel when the throttle was released. This frequently made it necessary to pause for a few seconds before engaging the power take-off for loading. This was a small fault in itself but very aggravating when experienced up to 70 times per day.

D.7 Fleet Attitudes

The City of Vancouver fleet was large in number and extremely diverse in types of vehicles and equipment employed. Because of this, the appearance of the two methanol trucks generated considerably less interest and curiosity than was the case in other project fleets. The trucks received little attention outside the department in which they were employed. All except routine maintenance tasks were carried out at the local Cummins dealer, so that the fleet workshop saw very little of the engines, although one or two repairs to the vehicle and body components were carried out. In addition, because of the additive enhanced fuel approach, the engines were virtually identical to a standard L10 diesel and the vehicles did not immediately stand out as different.

The short in-service history of these trucks in comparison to other project vehicles also meant that there was not time for the fleet to form a good overall impression of their capabilities during the period covered by this report. At an operating level the tendency for the engines to stall unpredictably and the slow hot-starting made for unpopularity with the drivers. The lack of a working fuel level gauge was also a source of annoyance, and drivers would tend to make unnecessary stops to refuel. However, it was discovered during the course of the project that the trucks were generally less popular because of their slightly longer wheelbase and wider turning radius which made for difficult maneuvering in the typical tight locations where garbage pickups were made. There were also other optional features of the specifications which were more appropriate for highway work and tended to be unreliable under the stop-start operating conditions. None of these particular problems were methanol related, but the combined effect was to generate a degree of driver prejudice against the trucks. The City of Vancouver vehicle operating and maintenance functions were divided, and when repairs were needed the operating department submitted the vehicle to the workshop and put a spare unit into service. As long as a spare was available there was little incentive to press for the return of the truck under repair. This made it fairly easy to ignore the absence of the methanol trucks for whatever reason.

The net result of this particular situation was that the fleet as a whole developed no strong attitudes either for or against methanol power. The operating staff and drivers were biased somewhat against the trucks up until almost the end of the reporting period, when some of the most annoying problems were cleared up. The maintenance staff did not deal with the actual methanol related problems, and the management was largely unaffected by the performance of the methanol trucks as long as spare diesels were available.

CHAPTER V: EMISSIONS

A. BACKGROUND

Concerns over the environment and the future supply of fossil fuel have helped focus public attention towards alternative fuels. In Canada, motor vehicle exhaust emissions represent the primary source of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). Table V-1 summarizes the breakdown for 1985. Although particulate emissions from motor vehicles constitute a small fraction of the total, they tend to be released at street level in an urban environment, making personal exposure all the more likely.

Table V-1. Emissions in Canada

Source	HC(1)	CO (kilotonnes)	NOx	Particulates
Light Duty Vehicles	668.3	5449.9	520.6	1.2
Heavy Duty Vehicles	63.6	435.5	285.7	21.8
Other Transport. (2)	48.3	249.7	188.0	5.6
National Total (3)	1797.9	1078.0	1959.3	2200(4)

Notes to Table:

(1) Non-Methanol HC
(2) Off road, Air, Marine and Rail
(3) All sources: transportation, industrial engines, fuel production and combustion, power generation, industrial processes and misc.
(4) Total particulate from all sources.

Amendments to the Canadian Motor Vehicle Safety Standards (CMVSS) have strengthened rules regarding exhaust emissions from light duty vehicles and heavy duty engines. The revised Canadian rules, effective in 1988, were adopted to maintain parity with U.S. standards. The amendments to rules covering heavy duty engines were the first change since controls were first introduced in 1975. The 1988 rules feature more stringent exhaust emissions levels, emissions measurement over a transient cycle and, for the first time for diesel engines, a limit to the mass of particulates that can be released. Future U.S. regulations will introduce even lower emissions levels phased in in two stages in 1991 and 1994. Table V-2 summarizes Canadian and U.S. standards. Any pending amendments to Canadian rules can be expected to at least match U.S. rules. Some consideration is being given to limiting carbon dioxide (CO_2) emissions.

The U.S. Environmental Protection Agency (EPA) has amended its rules (April 1988) to include motor vehicles powered by methanol. The California Air Resources Board (CARB) is currently drafting rules for methanol vehicles in its jurisdiction, and considering emissions regulations specific to gaseous fuels.

The regulatory approach to alternate fuels has typically been to impose the same emissions limits currently in effect for gasoline and diesel, i.e., set limits on the quantities of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx) and particulate matter (PM). However, there is a recognition that the photochemical reactivity of the hydrocarbon portion of the emissions from an alternate fuel can be different to that from gasoline or diesel. Current thought is along the lines of limiting the total HC emissions of an alternate fuel to an equal reactivity level to that of gasoline or diesel.

Table V-2. Summary of Heavy Duty Vehicle Engine Exhaust Emissions Regulations in Canada and U.S.

YEAR	TEST	FUEL(1) TYPE	HC	CO	NOx	PARTIC
				[G/KW HR.](2)		
Canada						
1988	Transient	D	1.7	20.8	8.0	0.8
USA(3)						
1988	Transient	D	1.7	20.8	14.2(4)	0.8
1991	Transient	D,M	1.7	20.8	6.7	0.34
	Transient	D,M	1.7	20.8	6.7	0.13(5)
1994	Transient	D,M	1.7	20.8	6.7	0.13(6)

(1) Fuel type: D=Diesel, M=Methanol. Methanol rules optional for 1990 Model year.
(2) 1G/KW Hr = 0.746G/HP HR.
(3) Applies to all states except California. Rules for California in 1988 are identical to Canada.
(4) By court order, 0.8gm/kw.hr level to be phased in 1990.
(5) Applies to urban transit bus engines only.
(6) Applies to all engines.

In order to incorporate methanol engines into existing categories, the EPA has ruled that the engine be subject to the following criteria:

- If the engine is run on the Otto cycle, it is subject to the same regulations as a gasoline engine.
- If the engine is run on the Diesel cycle (compression ignition), it is subject to the same regulations as a diesel.

The total HC's from methanol fuel are reported as organic material hydrocarbon mass equivalent (OMHCE) and calculated as:

$$\text{OMHCE} = \text{HC} + 0.433\,(CH_3OH) + 0.462\,(HCHO)$$

where HC = mass of hydrocarbons
CH_3OH = mass of methanol (unburned fuel)
HCHO = mass of formaldehyde
0.433 = ratio of Molecular Weight (MW) of current vehicle HC's to the MW of methanol
0.462 = ratio of MW of current vehicle HC's to the MW of formaldehyde.

B. PROJECT EMISSIONS TESTING

Emissions tests were performed on the Caterpillar, Cummins and ignition improved DDC engines. (New York). One Caterpillar engine was tested prior to its installation into Williams truck #289 and again following its removal from the vehicle. One Cummins engine was tested at ORTECH before installation in truck 875. The ORTECH test yielded 13 mode emissions profiles based on varying concentrations of Avocet. The engine will be retested at the conclusion of the program. The Kennedy Airport - DDC engine underwent emissions testing at Southwest Research Institute (SWRI) in Texas. The goal of this testing was to optimize the quantity of Avocet to be used during field trails. The engine had accumulated approximately 100 hours of operation on methanol prior to the emissions test. Table V-3 summarizes emissions tests carried out on MILE project engines.

Table V-3. Mile Emissions Tests

ENGINE	TEST	LOCATION	DATE
Caterpillar 3406B	13 Mode. Transient. Transient.	Caterpillar Inc. Caterpillar Inc. Caterpillar Inc.	Aug 1986. Feb 1987. Dec 1989.
Cummins L10	13 Mode. Transient.	ORTECH	Feb 1989. Retest scheduled for 1991
Kennedy DDC	Transient.	SWRI	Jun 1989

Table V-4 presents exhaust emissions data for MILE project engines. None of the engines used in MILE were production methanol engines. During the course of the project, a number of modifications were made to the Caterpillar and Cummins engines. However, these modifications were primarily for durability purposes and would not be expected to affect the emissions profile. The DDC engines used in Canada underwent a considerable number of changes aimed at improving durability, performance and emissions. Service and wear related emissions deterioration during the project could not be measured for the DDC engines. Engine specifications and power outputs at the end of the reporting period were quite different to those at the start.

The use of methanol resulted in significant particulate level reductions in all engines. The effect of methanol on the other regulated emissions was related to the ignition technique utilized. It is difficult to make direct comparisons of total hydrocarbon output, since rules relating to the reporting of hydrocarbons from methanol engines were only put into place in April 1989. The new rules limited the total organic mass hydrocarbon equivalent (OMHCE) of methanol vehicles. The OMHCE limit for methanol vehicles was established in order to limit the amount of organic carbon to that permitted from their diesel equivalents. Previously, hydrocarbons from methanol engines may have been reported on a diesel basis (via HFID) corrected for methanol.

Emissions results revealed that project methanol engines still typically produce a greater mass of hydrocarbons emissions than their diesel equivalents. Methanol engine development continues, and later versions of these engines have shown significant advances in emissions reduction during test work.

Table V-4. Mile Engine Emissions Test Results

FUEL TYPE	TEST CYCLE	HC(1)	CO	NOx	PM	ALD.	NOTE
		Unit: g/kW hr (= 0.746 g/bhp hr)					
Engine: Caterpillar 3406B (2)							
M	13M(3)	3.19	6.31	3.55	NA	0.09	
M	Trans	5.97(4)	16.55	4.09	0.20	0.66	
D	Trans	NA	2.86	8.04	0.54	NA	Range
			5.36	12.06	0.80		with
						diesel	
Engine: Cummins L10 (5)							
						(6)	
M	13M	3.75	2.01	6.41	NR	0.17	3% Avct
M	13M	2.10	2.04	7.29	NR	0.17	5% Avct
M	13M	1.69	1.94	7.40	NR	0.15	7% Avct
Engine: Ignition Improved DDC 8V-71(7)							
M	13M(3)	1.74	11.26	10.05	NA	NA	7.5% Avct
M	Trans	2.28	3.75	10.86	0.84	0.22	7.5% Avct
D	13M .	1.34	10.19	10.72	NA	NA	
D	Trans	2.41	5.63	10.72	1.07	0.24	
Engine: DDC 6V-92TA							
M	Trans	1.47	2.55	3.08	0.11	0.16	(8)
D	Trans	0.99	1.78	6.81	0.450	NA	(9)

Notes to Table:

(1) Reported as diesel HC's unless noted.

(2) Source: Caterpillar monthly reports (August 1986, February 1987).

(3) Engine build was subsequently modified prior to transient testing.

(4) Total hydrocarbon calculated as: OMHCE=0.433 (Methanol) + .462 (Formaldehyde) + HC's.

(5) Source: ORTECH (February, 1989).

(6) Formaldehyde levels.

(7) Source: Southwest Research Inst. Methanol results reported represent optimized Avocet concentration and timing (June 1989).

(8) Source: Released by DDC at May 1989 APTA conference, Orlando Fld. ("preparation build").

(9) Source: Communication with B.Fugoros-DDC (March 7, 1989.

The use of methanol in the Caterpillar and DDC 6V92 engine resulted in a slight increase in CO emissions, but these are still within 1994 EPA limits. NOx emissions with glow plug assisted methanol engines appeared to be lower than their diesel counterparts. This may have been related to the high heat of vapourization of methanol helping to reduce thermal NOx.

Ortech and Southwest Research Institute testing was directed at defining the optimum Avocet content for the Cummins and modified DDC engines. Emissions results presented in Table V-4 for the Cummins engine indicate the effect of a varying concentration of Avocet on emissions. The results revealed general trends for methanol additive engines. NOx emissions increased with increasing Avocet concentration while HC emissions were inversely affected. CO and aldehyde emissions appeared to be substantially unaffected by Avocet concentration in the range tested. At lower loads, combustion is more difficult to sustain as the Avocet concentration decreases, therefore HC levels tend to increase. Conversely, NOx emissions rise faster than load with increasing Avocet concentration. It is not possible to state whether the increased NOx emissions were due to fuel effects caused by nitrates in the Avocet or combustion effects due to increased Avocet concentration, and hence increased mixture explosiveness. Increasing Avocet concentration would enable the fuel to ignite more easily, but with a faster pressure rise, leading to higher in-cylinder temperatures and NOx formation.

C. ALDEHYDE EMISSIONS TESTING

The MILE program included development of equipment to sample vehicle exhaust for aldehydes in the field. In-service aldehyde field testing was intended to provide a measure of engine deterioration and basic information on aldehydes being released during engine idle. Aldehyde levels at idle are of particular concern to transit operators in Canada because diesel buses are started and warmed up indoors. Design and manufacture of the equipment was sub-contracted to the Manitoba Research Council (MRC). The Vehicle Emissions Test Laboratory (VETL) of Environment Canada performed calibration trials and data analysis.

Based on a review of available techniques for aldehyde sample collection, the 2,4 dinitrophenylhydrazine (DNPH) method was selected. This uses direct gas absorption on a solid absorbent with subsequent analysis via high performance liquid chromatography (HPLC). The DNPH method is an accepted procedure for aldehyde sample collection in U.S. emissions test protocol. For the purposes of Project MILE, the DNPH method was validated with two studies that looked at storage stability and the effect of transport on DNPH samples. The two studies examined five aldehydes; formaldehyde, acetaldehyde, acetone, acrolein and propionaldehyde. The results showed that all except acrolein remained stable when stored on DNPH cartridges for up to five weeks at temperatures of 21° C or less.

The sampling device was required to be portable, easily assembled in the field and low in cost. The final design consisted of an electrically driven diaphragm pump drawing raw exhaust through DNPH cartridges. Raw exhaust sampling was used because of the difficulty and expense involved in fabricating a portable exhaust dilution system. A solid desiccant and a sample line heater were used to remove moisture from the gas stream and prevent condensation. Figure V-1 is a schematic of the test cart.

Two cartridges in series were used for each aldehyde test in order to verify whether breakthrough occurred. Breakthrough refers to the condition when the exhaust gas exits the cartridge still laden with aldehydes. More than 95% of the exhaust aldehydes should be removed by the first cartridge and the remainder by the second. If aldehyde collection ratios were much different, the test was deemed unsuccessful. Breakthrough was attributed to an incorrect flow rate or aldehyde saturation in the first cartridge.

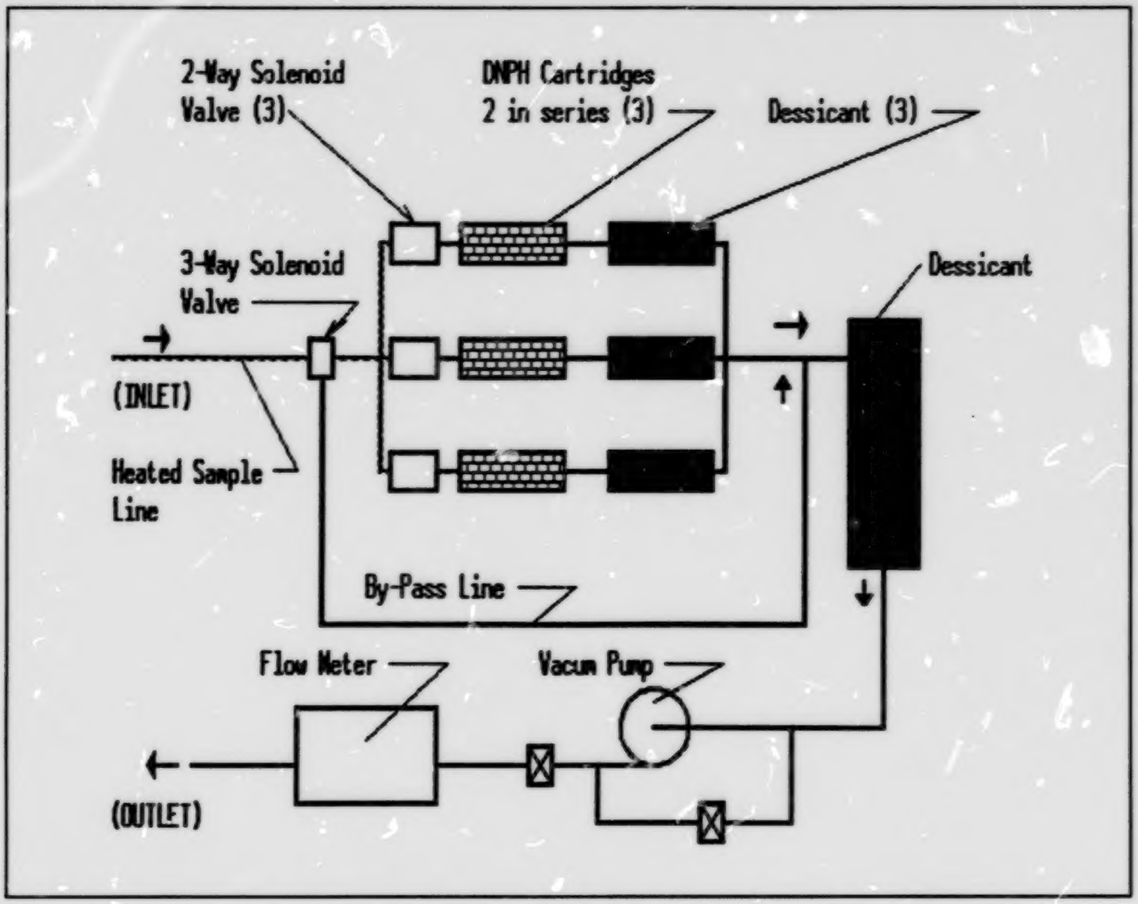
2-Way Solenoid Valve (3)
DNPH Cartridges 2 in series (3)
Dessicant (3)
3-Way Solenoid Valve
Dessicant
(INLET)
Heated Sample Line
By-Pass Line
Flow Meter
Vacum Pump
(OUTLET)

Figure V-1. Aldehyde Test Cart Schematic

Table V-5. MILE and VETL Comparative Aldehyde Test Results

Test No.	Formaldehyde Levels (ug/l)		% diff.
	MILE	VETL	
1	13.1	10.9	20
2	3.7	4.2	12
3	2.1	2.0	5

After the preliminary bench tests at MRC in Winnipeg, the test cart was shipped to VETL in Ottawa for an evaluation of the aldehyde sampling accuracy with respect to VETL's permanent instrumentation. VETL were actively involved in measuring exhaust aldehydes, as well as performing "round-robin" testing with the EPA.

Comparative testing was performed using a test car fueled by a 10% methanol and 90% commercial gasoline mixture. A transient driving cycle was used to warm the engine, then three parallel samples of raw exhaust were simultaneously taken during a hot idle. Analysis results are reported in Table V-5.

The variation of the measured aldehyde levels was judged to be within reasonable limits, allowing for the simple construction of the MILE test equipment.

Vehicles from Williams Moving and Storage, the City of Vancouver and Winnipeg Transit were tested periodically during 1989. The Medicine Hat Transit buses were not tested because their engines were similar to the engines in the Winnipeg Transit Fleet.

For each vehicle test, the engine was run at hot idle, and two separate aldehyde measurements were recorded within fifteen minutes of each other. The intention behind this approach was to establish the repeatability of results from the portable tester. The repeatability was found to be good for tests performed back to back, but poor for different test dates.

Data collected is reported in Table V-6 (Vancouver - Cummins), Table V-7 (Williams - Caterpillar), and Table V-8 (Winnipeg - DDC). The test procedure was deliberately made as basic as possible in order to facilitate sampling under field conditions. The column giving formaldehyde as a percentage of total aldehydes is significant. Formaldehyde constitutes over 90% of total aldehyde content under normal conditions, and results below this level cast doubt on the validity of the test involved.

During the test work, condensation was frequently observed in the sample inlet line. It is probable that some aldehydes dissolved in the condensation and so were not absorbed by the test cartridges. This would lead to test results below the actual engine output levels, and also cause some scatter depending upon the amount of condensation occurring and the amount of aldehyde which it absorbed.

For initial analysis purposes, it was assumed that the resulting error was the same for both methanol and diesel testing, since condensation occurred in both cases. Methanol to diesel aldehyde output ratios were calculated using this assumption, and are given in Table V-9.

The ratios may only be quoted in a range at this stage. The Caterpillar engines have been withdrawn and no further tests will be possible.

Further testing of the Cummins and DDC engines is proposed in order to improve the statistical significance of the results collected so far. Means to eliminate condensation in the sample line will be investigated, including shortening the line and applying more heating and insulation.

Table V-6. Aldehyde Emissions: City of Vancouver

Vehicle I.D. # (fuel)	Date Tested (mm/dd/yy/)	Test No.	Engine Temp.[a] (Celsius)	Aldehyde Emissions (ug/l)[b]		
				Formaldehyde	Total Aldehydes	Form. as a % of tot. Ald.
1874	09/19/89	1a	79	19	20	95
(M)		1b	79	16	17	94
	07/26/89	2a	82	2	3	66
		2b	82	8	8	100
	03/10/89	3a	69	3	6	50
		3b	93	3	7	43
1875	09/19/89	1a	75	28	29	97
(M)		1b	75	20	21	95
	07/26/89	2a	77	7	8	88
		2b	77	14	14	100
1878	09/19/89	1a	82	7	12	58
(D)		1b	82	4	7	57
	07/26/89	2a	82	31	37	84
	03/10/89	3a	79	*	*	—
		3b	79	*	*	—
		3c	79	*	*	—
	03/13/89	4a	78	5	18	28
		4b	80	7	21	33

a) The engine temperature remained constant during the sampling.

b) Units are in micrograms of aldehydes per litre of raw exhaust.

c) Indicates levels below detection limit.

Table V-7. Aldehyde Emissions: Winnipeg Transit

Vehicle I.D. # (fuel)	Date Tested (mm/dd/yy/)	Test No.	Engine Temp.[a] (Celsius)	Aldehyde Emissions (ug/l)[b]		
				Formaldehyde	Total Aldehydes	Form. as a % of tot. Ald.
601	09/21/89	1a	83	12	22	56
(M)		1b	83	9	20	45
	07/28/89	2a	81	38	42	90
		2b	81	34	39	87
602	09/21/89	1a	89	22	23	96
(M)		1b	89	12	14	86
	07/28/89	2a	85	34	40	85
		2b	85	33	38	87
603	07/21/89	1a	73	14	22	64
(D)		1b	73	14	16	88
	07/28/89	2a	85	25	28	89
		2b	85	28	30	93

a) The engine temperature remained constant during the sampling.

b) Units are in micrograms of aldehydes per litre of raw exhaust.

Table V-8. Aldehyde Emissions: Williams Moving & Storage

Vehicle I.D. # (fuel)	Date Tested (mm/dd/yy/)	Test No.	Engine Temp.[a] (Celsius)	Aldehyde Emissions (ug/l)[b]		
				Formaldehyde	Total Aldehydes	Form. as a % of tot. Ald.
272	04/28/89	1a	96	13	13	100
(M)		1b	95	13	14	93
		1c	82	19	19	100
289	07/26/89	1a	90	28	29	97
(M)		1b	90	28	28	100
	04/26/89	2a	87	11	13	85
		2b	89	12	12	100
		2c	90	32	32	100
	01/26/89	3a	89	4	4	100
		3b	89	9	10	90
205	07/25/89	1a	85	1	1	100
(D)		1b	85	1	2	50
	05/04/89	2a	72	5	6	83
		2a	75	8	10	80

a) The engine temperature remained constant during the sampling.

b) Units are in micrograms of aldehydes per litre of raw exhaust.

Table V-9. Methanol to Diesel Aldehyde Emission Ratios: Preliminary Results

Fleet	Engine Type	Range of Aldehyde Ratios
City of Vancouver	Cummins L10TA	4 to 13
Williams M & S	Cat 3406DITA	1 to 25
Winnipeg Transit	DDAC 6V-92TA	1 to 3

CHAPTER VI: FUEL FORMULATION

A. INTRODUCTION

The project MILE fuel formulation program examined the question of how the physical and chemical properties of methanol might be changed to make it more suitable for use as a heavy vehicle fuel. The intention was to identify additives which could be used to enhance desirable properties or eliminate undesirable properties. The work was divided into three phases.

Phase I was a completely theoretical study and listed all of the properties of methanol relevant to use as a fuel. After the list was completed the properties which could reasonably be expected to be modified by additives were identified.

Phase 2 consisted of a search for potential additives to address the issues revealed in Phase I. Phase 3 included the planning and execution of laboratory tests to examine the effects of the proposed additives.

Three properties were identified for intensive examination:

- Taste and Odour
- Flame Visibility
- Lubricity

The first two properties were critically involved in safety of fleet operations. Fuel lubricity was expected to be a major influence on the life of fuel pumps and injectors.

The fuel formulation work was carried out by three project sub-contractors, Manitoba Research Council (MRC) of Winnipeg, the University of Manitoba and Shell Canada Oakville. SMI also engaged Econotech Services Ltd. of New Westminister, B.C. for later follow-up work.

B. FUEL PROPERTIES

Phase I of the program identified 26 properties that affect methanol's suitability as a fuel. These properties are summarized for methanol and diesel fuel in Table VI-1. Fluid, thermal, and combustion properties have a direct influence on engine design and performance. Properties having a bearing on safety issues were also given consideration.

The fuel property listing was used to evaluate, from a theoretical point of view, how a specific property would affect vehicles and fleets if methanol was used in place of diesel. The evaluation used the premise that fuel substitution occurred in a diesel engine which had undergone minor modifications; the most likely near term type of methanol engine. The results of a transition from diesel to methanol were classified as advantageous, neutral or detrimental for each property.

Situations where the change from diesel to methanol proved to be advantageous or neutral were classified as "additive not required". An example of this is melting point. Methanol has a discrete freezing point of -95.5°C and no pour point compared to diesel, which begins to form wax and increase in viscosity as the temperature decreases.

A situation classified as "little benefit" was one that would require an excessive quantity of additive to effect a change, or one which improved one property but had adverse effects on other properties. Some properties could be better addressed through an engine design change. Finally, some properties cannot be changed through the use of an additive at all.

Table VI-1: Methanol and Diesel Fuel Properties

Properties	Diesel	Methanol
Fluid		
1) Pour point (°C)	-12 (summer) -40 (winter)	--- ---
2) Melting point (°C)	---	-95.5
3) Solvent Characteristics		
Solubility Parameter[2]	7 - 9 (est)	14.5
4) Solubility in Water	Very Low	Miscible
5) Corrosiveness	Low	High
6) Relative density		
Rel d (L) 20/4 (°C) (water = 1)	0.84	0.7915
Rel d (g) 15 (°C) (air = 1)	---	1.106
7) Viscosity (cSt @ 38°C)	1.4 - 5.8	0.5
8) Lubricity	High	Low
Thermal and Combustion		
9) Heat Capacity		
Liquid (kJ/kg K)	2.0 (mid bp)	2.3
Gas (kJ/kg K)	---	1.36 (25°C)
(@ 15.6° C)[3]	1.6	1.72
10) Critical Temperature (°C)	---	239.4
11) Boiling Range (°C)	160 - 360	65
12) Flash Point (°C)	70[4]	12
13) Flammability Range (% volume)	0.6 - 6.5	6 - 50
14) Cetane Number	30 - 50	0 - 5
15) Autoignition Temperature (°C)	316 245[4]	470
16) Heat of Vapourization		
H vap (kJ/kg)	285 (37.8°C)	1089
17) Heat of Combustion		
Q gr (1) (MJ/kg) (gross)	45.30	22.68
Q net (1) (MJ/kg)	42.50	19.93
Q net (1) (MJ/L)	35.70	15.77
Net MJ/kg stoic. mix	2.74	2.67
18) Reid Vapour Pressure	---	32
19) Stoichiometric Air/Fuel Ratioo		
(a/f)s mass	14.49	6.46
20) Product/Reactant Ratio		
(P/R)s molar	1.06 (est)	1.061
21) Molecular Weight	226 (cetane)	32
H/C ratio (atomic)	1.83	4
22) Minimum Ignition Energy (mJ)	0.3[5]	0.21[6]
Safety		
23) Flame Luminosity	High	Almost Invisible
24) Odour Level	High	Low
25) Palatability (drinkability)	Low	?
26) Toxicity[7]	Carcinogen	Non-Carcinogen
Acute Local		
- Irritant	Slight	Slight
- Inhalation	---	Slight
Acute Systemic		
- Ingestion	Moderate	Severe
- Inhalation	Moderate	Moderate
- Skin Absorption	---	Moderate
Chronic Local		
- Irritant	Moderate	Slight
- Inhalation	---	Slight
Chronic Systemic		
- Ingestion	---	Moderate
- Inhalation	Severe	Moderate
- Skin Absorption	---	Moderate

Three properties where an additive could prove beneficial were selected for further study. These included fuel lubricity, flame luminosity and odour level.

In depth studies were subsequently performed to identify potential methanol malodourants, flame luminosity enhancers and lubricity enhancers.

B.1 Additive Properties

Desireable properties of potential additives include:

(1) The additive must be physically and chemically compatible with methanol.

(2) The additive should have the same or higher specific energy content as methanol.

(3) The additive should be relatively inexpensive.

(4) The additive must not be readily removeable from the fuel.

(5) The additive must not significantly add to exhaust emissions.

(6) The additive must not leave a residue in fuel systems and filters.

(7) The additive must not complicate regulatory compliance.

C. FUEL MALODOURANT STUDY

Fuel malodourant testing was subcontracted by the MRC to the Department of Foods and Nutrition of the University of Manitoba. A total of seven potential malodourants was selected for evaluation. Testing was designed to determine the odour detection threshold of the malodourant in methanol, and rank the relative odour of the mixture.

Test results are presented in Table VI-2. The threshold detection level for methylal remains uncertain since more than 75% of the panelists were able to detect its presence at 0.31% (v/v), the lowest concentration tested. Butanethiol provided a strong odour intensity at a very low concentration. Trimethlylamine produced the lowest odour intensity, but was tested at an extremely low concentration. Pyridine produced a moderate odour at a low concentration. N-Butylamine and diethylamine both gave a moderate odour. However, these two malodourants were tested at higher levels compared to the others. The use of napthalene is better avoided since it is a relatively common odourant and its use may lead to confusion. Organic sulfates and mercaptan were ruled out as possible malodourants for the same reason.

D. FLAME LUMINOSITY

Investigation initially centered around quantifying the flame luminosity of methanol and methanol plus additives. Luminosity testing used mixtures of up to 10% additive in methanol.

A photometer-luminance probe was used to record the amount of light emitted by burning test mixtures. Each test burn was conducted indoors, under reduced ambient lighting. Over 100 burns were carried out using different potential additives.

The average flame luminance of methanol was recorded as 0.39 ft. lamberts. Gasoline had an average luminance of 358 ft. lamberts; nearly 1,000 times greater than neat methanol. M85, a mixture of 85% methanol and 15% gasoline, gave a flame luminance of 3.29 ft. lamberts.

Table VI-2: Methanol Malodourant Study Test Results

MALODOURANT	THRESHOLD CONCENTRATION (V/V%)	ODOUR INTENSITY(1)	AT CONCENTRATION (V/V%)
BUTANETHOIL	1.2E-5	4.2	2.4E-5
NAPTHALENE	9.75E-3 (W/V%)	4.1	1.1E-2 (W/V%)
METHYLAL	<0.31	3.4	0.31
DIETHYLAMINE	0.133	3.1	0.20
PYRIDINE	1.9E-2	2.9	2.5E-2
N-BUTYLAMINE	9.4E-3	2.8	0.125
TRIMETHYLAMINE	1.83E-6	2.4	2.0E-6

(1) ODOUR INTENSITY: 1 = No Odour
6 = Very Strong Odour

It was found that methanol additive mixtures showed either fuel distillation effects or a low overall flame luminance. Neat methanol is a discrete substance with a unique boiling point. With an additive, the resultant mixture had at least two boiling points. Fuel distillation would occur if the boiling point temperatures of the individual substances were far enough apart. The component with the lowest boiling point would burn off first. If the components had significantly different flame luminances, the effect would be a marked change in flame luminance over the course of a burn as one component burned off and the next heavier component began to burn. These situations tended to be characterized by a blue flame while the methanol portion of the mixture burned and an orange-yellow flame while the additive component burned. A substance containing a range of boiling points, such as gasoline, tended to temper this effect. A mixture of methanol and gasoline, M85, yielded an interesting effect. Two discrete peaks were observed. Initially, the very volatile components of gasoline burned off, followed by methanol-gasoline until the very end when the higher boiling point hydrocarbons and tars burned off. Nigrosine, a powdered black dye ($C_{48}H_{55}N_9$), allegedly soluble in methanol, was the only additive that produced a fairly stable flame luminance, albeit relatively low. Nigrosine was the subject of follow-up work.

The average flame luminance of all mixtures tested was extremely low. The majority of additives failed to achieve even 1/10 the average flame luminance of gasoline. Table VI-3 presents a summary of the average flame luminance and observations for selected additives. A general review of all the results indicated that those additives that did offer increased average flame luminance also showed fuel distillation effects.

Initial testing was concerned with quantifying the flame luminance of different methanol-additive mixtures. The follow-up study focussed on nigrosine, because it offered a relatively steady luminance and a 34 fold increase in flame luminance compared to neat methanol. Since nigrosine is a solid substance more information was required before any engine testing could be performed regarding solubility and tendency to settle out.

The results were disappointing. Neither a mixture of 1% W/V nor even 0.1% W/V nigrosine in methanol were found to be fully soluble. Even after agitation of the mixture, residue in the range of 3.5 mg/l for 0.1% W/V nigrosine to 59 mg/l for a 1% W/V nigrosine mixture was detected. The bulk of the particles in the 1% nigrosine mixture were in the 1 to 2 micron size range.

Results from the flame luminance work leave the issue of luminosity unresolved. The issue of flame luminosity is a subjective matter. There is no standard for a visible flame.

The work under the MILE program sought to identify a potential additive that provides a fairly uniform luminance over its entire burn period. An alternative could be to focus on an enhancer that provides a luminous flame at the start of combustion, the rationale being that upon ignition the fire will be visible. The fire would then remain visible only if it were to subsequently ignite other combustibles that produce visible flames and/or smoke. While this rationale may be reasonable under certain circumstances, it is still far from an ideal solution and may not satisfy all concerned parties.

E. FUEL LUBRICITY

A laboratory study was undertaken to examine the lubricating effects of methanol and methanol plus various additives on the fuel injection system of a diesel engine. A specially developed test rig was used for the majority of the tests conducted. This study was supplemented by ball on cylinder lubricity evaluator (BOCLE) tests.

Table VI-3. Summary of Flame Luminosity Test Results

FUEL	AVERAGE LUMINANCE	OBSERVATION
Winter Grade Gasoline	358	Yellow Orange flame,smoke given off.
Commercial grade methanol	0.39	Blue flame, a few yellow streaks.
	Methanol Mixtures	
M85 (85%M, 15%WGG)	3.29	Yellow orange flame for 15-20 seconds and during last seconds of burn.
6% Octanol	26.0	Blue flame Yellow orange streaks. Yellow orange flame for the last 34-40 sec. Smoke given off.
9% N-Pentanol	18.6	Blue flame, occasional yellow orange streaks. Yellow-orange flame last 20 sec.
9% 2-Butanol	4.46	Blue flame, occasional yellow streaks during last 40 sec.
1% (W/V) Nigrosine	13.4	Yellow orange flame

[All mixtures V/V unless otherwise noted]

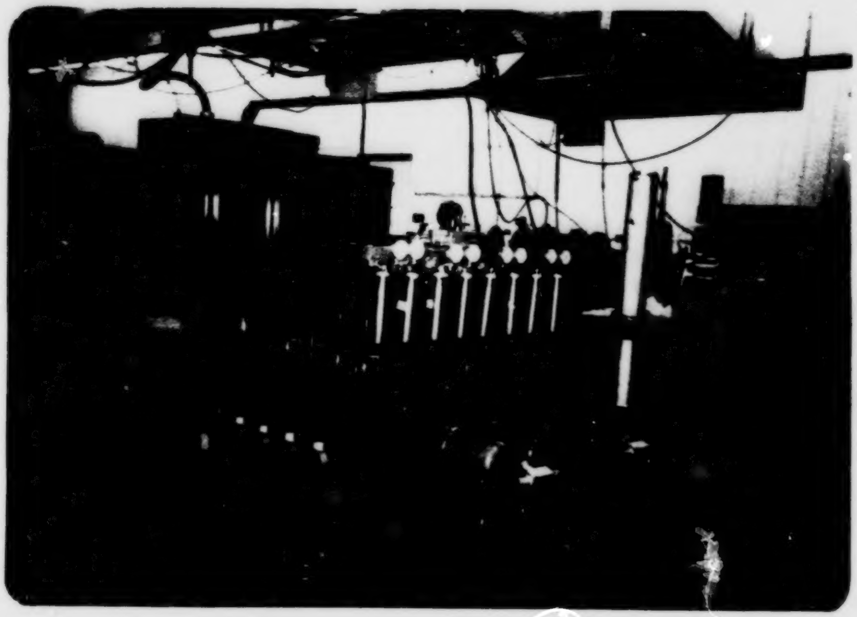

Figure VI-1. Fuel Lubricity Test Rig

Figure VI-2. Fuel Lubricity Test Rig

The lubricity test rig consisted of a Detroit Diesel 8V-92 engine which had been modified to permit different fuels to be circulated through each fuel injector. An electric motor drove the camshafts of the engine enabling the fuel injection mechanism to operate. The injectors used were DDC Model C-55 mechanical unit injectors.

All testing on the rig was carried out at maximum rack with the camshaft motored at a constant speed of 1800 RPM.

Figure VI-1 and VI-2 show the project lubricity test rig. Each of the eight injectors had an individual fuel tank, electric fuel pump, filter unit and pressure monitoring circuit. Each fuel tank was provided with a thermostatic heater unit to maintain fuel temperature at typical engine operating levels.

The BOCLE test procedure employed was the "Proposed standard test method for measurement of lubricity of liquid hydrocarbon fuels by ball on cylinder lubricity evaluation-Draft No. 10." (ASME)

E.1 Results

Test Fuels

Table VI-4 gives a synopsis of all fuels evaluated and the test method employed. Diesel and 100% methanol were tested first to provide baseline information. Potential additives were selected through a literature search conducted by the MRC. Avocet and Maxlube were evaluated since they were used in the Cummins L-10 and Caterpillar 3406 DITA methanol engines. Pipeline methanol was methanol that had been pumped through a pipeline in COFA tests and had a slight golden tint because of the hydrocarbons it had picked up.

The BOCLE test was used to prescreen a batch of 12 potential additives. The results are presented in Table VI-5. The table ranks the fuels tested from the most desireable (top) to least desireable (bottom) based on wear scar diameter. Interestingly, the BOCLE ranked chemical grade methanol as being better than diesel. However, the BOCLE addresses wear and not friction or pounding. Fuel wetted areas inside injectors undergo cyclic friction between the sliding surfaces of the plunger and barrel and between the needle valve and spray tip. Pounding occurs at the tip of the needle valve and spray tip, also referred to as nozzle seat area. Thus, while the BOCLE results may give some indication of the relative wear, they failed to fully address the situation inside an injector.

The lubricity test rig was designed to simulate a working engine. However, results obtained from the lubricity test rig were contradictory to experience obtained in the field. When tested on the lubricity test rig, all fuels with the exception of diesel failed to provide satisfactory performance. An injector failure was defined as a plunger seizure or failure of an injector to atomize fuel at the test conclusion. ("POP" test) Test results showed that injectors run on neat methanol were unable to atomize fuel within 20 hours of operation, in marked contrast to an operational life of up to 1000 hours in the field. Although the lubricity test rig utilized DDC mechanical injectors as opposed to DDC electronic injectors, both types of injectors operate in a similar fashion. The plunger compresses the fuel and sends it into the spray tip. The actual injection occurs when the needle lifts and the spray holes open, allowing fuel into the cylinder.

Table VI-4. Test Fuels Matrix

FUEL	LUBRICITY TEST RIG	BOCLE	COMMENT
Diesel Fuel	X	X	Baseline case
Neat Methanol	X	X	Chemical grade methanol
Methanol			
+3% Castor Oil	X	X	
+5% Avocet	X	X	Fuel mix used in Cummins L-10 engine
+0.025% Maxlube 8027	X	X	Fuel mix used in Caterpillar 3406 DITA
+40PPM Hitech 515	X	X	
+32PPM Hitech 560		X	
+1% Neo-Fat 94-06		X	
+3% Neo-Fat 94-06		X	
+3% Armeen D		X	
+1% Armeen D		X	
+10% Glycerol	X		
Pipeline Methanol		X	From COFA Pipeline test

Table VI-5. BOCLE Test Results

RANK	DESCRIPTION	AVERAGE WEAR SCAR DIA - (mm)
1	Methanol + 40ppm Hitec 515	0.39
2	Methanol + 1% Neo-Fat 94-06	0.41
3	Methanol + 32ppm Hitec 580	0.43
	Methanol + 0.025% Maxlube	0.43
4	Methanol + 3% Armeen D	0.44
5	Methanol + 3% Castor Oil	0.45
6	Methanol + 3% Neo-Fat 94-06	0.47
	Methanol + 1% Armeen D	0.47
7	Neat Methanol	0.53
8	Diesel Fuel	0.58
	"Pipeline" Methanol	0.58
9	Methanol + 5% Avocet	0.73

One possible explanation for the apparent lack of correlation between the field and test rig is the whole theory of fuel atomization and how it applies to the methanol engine. The diesel engine requires the fuel to be atomized in order to disperse the fuel upon injection, achieve good air-fuel mixing, and increase the fuel surface area to volume ratio to ensure complete combustion through self ignition. As diesel injectors deteriorate, the operator may notice a lack of power, increasing black smoke, increased fuel consumption, poorer starting and higher operating temperatures. In the case of a methanol engine, there has been a great deal of concern on the part of engine manufacturers to accommodate methanol's higher heat of vaporization and lower cetane rating, by the use of ignition aids such as glow plugs, spark plugs, etc.

Perhaps as the methanol is injected into the already hot combustion chamber, it instantly flashes into vapour, therefore negating the need for atomization as with diesel fuel.

All that is ideally required is sufficient swirl or mixing to ensure distribution of the fuel vapour for a more even air fuel ratio and more efficient combustion. This argument may hold for neat methanol or methanol plus low concentration additives. If the additive concentration is increased and the additive has properties similar to diesel, a situation more akin to the diesel may develop. In other words, upon injection, atomization may be required to break up the fuel and ensure that the heavier droplets have the momentum to penetrate further into the combustion chamber while the lighter more volatile droplets initiate combustion. Therefore, it may be possible to run methanol engines with lower injection pressures thereby reducing fuel injection component costs through simplification of injection systems.

F. SUMMARY OF FINDINGS

1. Lubricity, critical temperature, flame luminosity and odour were identified from a list of 26 properties of methanol as potential candidates for modification by additives. The remaining properties were classified as either not requiring modification, modification would produce little benefit or could not be modified by additives.

2. Two fuel properties, fuel odour and flame luminosity, are safety issues which are best addressed through additives.

3. The use of additives for safety related issues ensures a uniform approach for all those likely to come in contact with the fuel; suppliers on through to end users.

4. Any contemplated fuel malodourant must provoke a unique and offensive enough odour to command instant recognition by the public. A secondary effect of an offensive malodourant must be to deter ingestion of the fuel. Of the malodourants tested, butanethiol appears to be most promising.

5. Nigrosine, an intense black dye that had initially been identified in earlier Project MILE literature as a potential flame luminosity enhancer, is not a viable additive because of its insolubility in methanol.

6. Fuel distillation effects will directly impact the flame luminance of a methanol-additive fire. Before a standard flame luminosity additive can be adopted for methanol, the qualitative issues of what constitutes a visible flame and whether a variably luminous flame is acceptable must be addressed.

7. No correlation of injector life between actual field experience with MILE engines and laboratory lubricity tests was established. The concept of fuel atomization and injector performance criteria in diesel engines may not be relevant for methanol engines.

G. RECOMMENDATIONS

Any contemplated methanol additive must be evaluated in the overall context of fuel handling, engine performance and economics. This includes any material compatibility or safety precautions different from the neat methanol or baseline diesel case. Engine performance includes any potential engine durability, emissions or fuel consumption problems. The total costs of using any additive must be weighed, including fuel distribution and handling.

CHAPTER VII: LIFE CYCLE COSTS AND BENEFITS

A. INTRODUCTION

This chapter examines the expected life cycle costs of operating heavy-duty vehicles using methanol in comparison with vehicles using diesel fuel. A subsequent section outlines the potential benefits of using methanol, particularly environmental effects.

Two scenarios have been selected to compare vehicle life cycle costs. The first is a transit fleet of 200 buses, using the DDC 6V-92TA engine, operating in the province of Manitoba. The second is a truck fleet of 10 vehicles operating over an intercity route in British Columbia. Both these scenarios reflect MILE demonstration experience.

The baseline case uses current (1990) model diesel engines, which conform to Canadian 1988 exhaust emissions standards. Costs for methanol engines are based on experience gained from the MILE project. However it is recognized that the actual costs involved in operating the MILE engines were high because of the prototype stage of the technology, the high cost of special spare parts, and the frequent need for advice and assistance from factory and dealer support services. The reliability of methanol engines in general improved greatly during the project. Eventual production engines may be expected to advance further still. The methanol engine costs used for comparison have been adjusted for expected future developments, taking into account the views of the manufacturers involved. Current diesel engines will undergo considerable changes in order to meet 1991 and 1994 U.S. exhaust emissions standards. Particulate traps may be required and low sulphur fuel will certainly be necessary. As a result, the cost of diesel operations will increase significantly. The cost study includes a sensitivity analysis in which the cost of methanol is compared with the diesel costs anticipated to meet 1991 bus and 1994 truck standards.

With regard to costs, the analysis in this chapter examines the differential, or incremental, costs between diesel and methanol technology. All costs are determined in constant (1990) value dollars. All capital costs are amortized, as a series of equal annual costs, over the expected life of the asset in question. The interest rate used to determine the annual amortized cost is derived from the following formula:

$Ri = ((1 + H)/(1 + Ir)) - 1$
where:

Ri: Real Interest Rate;
H : Nominal interest rate;
Ir: Inflation rate.

Two types of cost analysis are included. The financial cost analysis is conducted from the view point of the fleet operator. This includes all applicable fuel taxes. The economic cost analysis considers the perspective of government policy makers and excludes fuel taxes.

The proposed Goods and Services Tax will bring about major changes in the Canadian taxation system, including taxes imposed on alternative fuels. Insufficient information is available concerning the effects of this tax on the situation under review. This analysis assumes that current Canadian taxation rules remain valid for the entire vehicle life cycle.

B. INCREMENTAL VEHICLE CAPITAL COSTS

B.1. Engines

Two types of engine are considered: the DDC 6V-92TA, widely used in Canadian transit buses, and the Caterpillar 3406B, which is a popular choice for heavy trucks. These two engines are fundamentally different in design, and the expected incremental costs show corresponding differences.

DDC 6V92TA Engine:

Modifications made to operate this engine on methanol included:

- provision of glow plugs, control module and associated electrical control circuits;
- provision of a blower air bypass system to control scavenge air flow at low speeds;
- provision of separate electrically-driven fuel pump and fuel cooler;
- high flow rate injector nozzles and methanol compatible fuel lines;
- provision of special fuel filter assemblies.

Detroit Diesel Corporation estimates that a production version of the methanol 6V-92TA engine would cost $4,000 to $4,500 more than the diesel equivalent.[1] This figure agrees with costs first predicted by General Motors at a Joint Hearing before the Fossil and Synthetic Fuels and the Energy Conservation and Power Subcommittees in the U.S. in 1984. G.M. predicted an incremental price of a methanol engine between $3,000 and $4,000 (1984 dollars) for production of between 250 and 300 engines per year.[2] DDC is actively preparing to market a methanol engine in 1991, and has already supplied over 50 pre-production engines to fleets throughout the U.S.A. and Canada.

Caterpillar 3406B Engine:

Modifications carried out to convert this engine from diesel to methanol included:

- provision of glow plugs and control system;
- provision of a second alternator to power the glow plugs;
- minor modifications to the injectors, fuel lines, and fuel pump including the use of methanol compatible materials;
- installation of a methanol compatible fuel filter assembly;
- installation of separate fuel injection pump lubrication system.

Caterpillar would expect to make several improvements in a production version of the engine, including substitution of valve and valve seat materials, and piston design changes. The separate fuel pump lubrication system would probably not be used on a production engine. The anticipated production modifications would not add substantially to the final market price. Caterpillar estimates that the incremental cost of a production version of the methanol engine would be about $1,100 more than the existing (1990) version of the 3406B diesel engine.[3]

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[1] January 9, 1990, telephone conversation with Mr. Roger Parry during which the estimated production cost of a methanol engine was given as 25% above that of the current diesel engine. The current Canadian over-the-counter price of a DDC 6V92TA diesel engine is $20,000 to $22,000.

[2] Alson J.A., Moving America to Methanol. University Press. Ann Arbor 1985.

[3] Telephone conversation. Mr. Bernie Richards, Development Engineer, Catepillar Inc. January 1990.

B.2. Vehicle Body and Chassis

The major chassis modification required for a methanol vehicle is provision of a larger capacity fuel tank. Approximately 2.25 times the diesel fuel capacity is required to maintain the same range capability. Project vehicles were provided with custom built stainless steel tanks. Terneplate, a tin plated sheet steel often used in vehicle fuel tanks, is definitely not acceptable for methanol use. Plain carbon steel with an external anti-corrosion coating may be acceptable, and methanol fuelled cars are increasingly using polyethylene tanks. At present it is suggested that stainless steel is the preferred material for a methanol truck or bus fuel tank. Material changes may also be required in the fuel feed and return lines and fittings.

Incremental Bus Body Costs:

Diesel transit buses are typically equipped with a 454 litre fuel tank. A 1,100 litre methanol tank would be required to provide the same vehicle range. Installation of the larger tank would require modifications to the bus body and frame. The unibody or semi-monoque designs currently used by bus body manufacturers allow limited scope for additional fuel tanks, due to the presence of underbody bulkheads and other essential structural and mechanical components.

Medicine Hat Transit purchased three methanol powered buses from Motor Coach Industries (MCI) in December 1989, with assistance from Energy, Mines & Resources. The cost of each of these three special production methanol buses was $82,000 over that of an equivalent diesel-powered bus. Subsequently, Medicine Hat placed an order for an additional three methanol buses. MCI set the price of the second batch of buses at $45,000 above that of a comparable diesel bus. MCI has acknowledged that the cost of the second set of three buses is above what they expect a production version of a methanol bus to cost, but is unable to furnish a future production cost figure. MCI based the cost of these buses on:

- the incremental cost of the DDC 6V-92TA methanol engine;
- prototype engineering and design costs
- non-routine production line assembly costs
- protection against unusual warranty and/or liability costs

One of the bids to supply 50 methanol powered school buses to a large scale program starting up in California was priced at 10% over the cost of the equivalent diesel bus. California school buses are very close in design to city transit buses.

This analysis estimates that the final production cost of a methanol transit bus would be 10% above that of the equivalent diesel bus, or $20,000. on a typical diesel cost of $ 200,000. The production DDC methanol engine will account for $4000 of the $20,000 increase, and the modifications to the bus chassis will total approximately $16,000.

Incremental Truck Chassis Costs:

A truck chassis is typically designed to accept a wide range of fuel tank capacities according to customer requirements. Chassis modification would not be necessary. Fuel tanks are frequently made from aluminium, which could not be used for methanol. MILE project trucks carried twin stainless steel fuel tanks, which cost $ 1,250 each. This analysis assumes that the extra cost of mounting brackets and dual piping systems would be compensated by the value of the deleted aluminium tank. This suggests that the incremental cost may be taken as the extra purchase cost of the tanks alone, or $ 2,500.00.

Table VII-1. Incremental Capital Costs

Cost Element	Bus	Truck Tractor
Engine	4,000	1,100
Body	16,000	2,500
Total	$ 20,000	$ 3,600
Annual Amortized		
- engine	660	293
- body	1,545	414
Total	$ 2,205	$ 707

MAJOR ASSUMPTIONS

Assumption	Bus	Truck Tractor
Nominal Interest Rate (H)	12%	16%
Inflation Rate (Ir)	5%	5%
Real Interest Rate (Ri)	6.6%	10.4%
Engine Life	8 yrs	5 yrs
Vehicle Life	18 yrs	10 yrs

B.3. Summary of Incremental Vehicle Capital Costs

Table VII-1 summarizes the incremental capital costs for a bus and a truck on a per vehicle basis. The total incremental capital cost for a bus is $20,000, and for a truck $ 3,600. The annual amortized costs for each vehicle are also shown. The annual amortized cost for the bus is $2,205, and for the truck is $707.

The amortized costs are based on the following assumptions. Transit buses in Canada are owned by municipalities and frequently subsidized by the provincial government. Financing is usually arranged through a bond issue which is about two percentage points below the prime interest rate. A trucking company would represent a higher risk, and would probably pay two points above the prime rate. These nominal interest rates were adjusted for inflation to arrive at the real interest rates. The interest rates and other assumptions made in calculating annual amortized costs are shown in Table VII-1.

C. INCREMENTAL VEHICLE OPERATING COSTS

Incremental operating and maintenance (O&M) costs associated with methanol fuelled vehicles are primarily associated with changes in fuel cost, and the different maintenance requirements of the engines.

C.1. Fuel Costs

Transit Bus:

The study assumes that a transit bus covers 60,000 kilometres per year. The theoretical volumetric fuel consumption ratio, based on energy content, is about 2.25 litres of methanol to 1 litre of diesel. In Project MILE, the Winnipeg demonstration vehicles consistently returned a fuel consumption ratio between 2.6 and 2.7 over approximately 200,000 kilometres of operation. The engines used in the project were not optimized for fuel economy. A production engine could be expected to use less fuel. DDC has established equal energy consumption as a production target, and has approached the 2.25 to 1 ratio in dynamometer tests. This analysis assumes that a production version of the DDC 6V-92TA methanol engine will achieve a 2.30 to 1 volumetric fuel consumption ratio.

The diesel fuel consumption rate is based on Project MILE experience in Winnipeg and Medicine Hat. Medicine Hat diesel control buses averaged 55.0 litre/100 km. Winnipeg diesel control buses averaged 52.0 litre/100 km. The rate for Winnipeg is used in the analysis. Hence the methanol consumption rate is calculated as 52 litre/100 km x 2.30 = 119 litre/100 km.

The diesel fuel prices used are based on quotes for bulk delivery contract purchases during November 1989.[4]

The methanol price is estimated on a gate purchase price, plus national and local delivery charges. The gate purchase price was provided by the Canadian Oxygenated Fuels Association (COFA). It is based on a long-term supply contract (at least 5 years) and corresponding expansion of production facilities at an existing methanol plant in Alberta. Methanol delivery to Winnipeg is assumed to be by rail to a bulk central depot, with local delivery by truck, at a combined overall cost of 4 cents per litre from plant to bus garage.

Table VII-2. presents the annual fuel costs per vehicle. The table shows the financial cost, which includes fuel taxes, and the economic cost, excluding taxes. Using the price assumptions mentioned, it would cost the fleet operator approximately $3,500 more per year per bus to operate on methanol fuel instead of diesel. For a 200 bus fleet, this represents an additional $690,000 O&M expenses. When fuel taxes are excluded, methanol fuel is roughly twice the cost of diesel fuel. These findings assume that both diesel and methanol prices remain constant. We will test this assumption in a later part of this chapter.

Truck:

The annual mileage of a representative truck is taken as 180,000 kilometres, corresponding to the annual distance accumulated by each MILE methanol truck. The average volumetric fuel consumption ratio during the 20 month duration of the fleet trial was 2.42 to 1. Caterpillar has achieved a 2.24 to 1 volumetric ratio during dynamometer testing. This analysis assumes that appropriate development work will give a 2.30 to 1 ratio from a production engine.

Project MILE control diesel trucks returned an average 46.4 litre/100km fuel consumption. The expected methanol consumption rate is therefore calculated as 46.4 x 2.30 = 106.7 litre/100km.

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[4] Energy Pricing News. Refined Fuel Report. Volume 9, No. 11. Southam Communications Ltd.

Table VII-2. Bus Fuel Costs
($/l)

	FINANCIAL COSTS		ECONOMIC COSTS	
	Diesel	Methanol	Diesel	Methanol
Plant Gate	-	0.150	-	0.150
Distribution	-	0.040	-	0.040
Delivered Cost	0.220	0.190	0.220	0.190
Federal Sales Tax*	0.027	0.026	-	-
Federal Excise Tax	0.040	-	-	-
Provincial Sales Tax	0.099	-	-	-
Total Cost Per Litre	$0.386	$0.216	$0.220	$0.190
Total Fuel Consumption/Yr	31,200 litre	71,760 litre	31,200 litre	71,760 litre
Total Cost/Vehicle/Yr	$12,043	$15,500	$6,864	$13,634

* (13.5% on the price of methanol)

Table VII-3. Truck Fuel Costs
($/l)

	FINANCIAL COSTS		ECONOMIC COSTS	
	Diesel	Methanol	Diesel	Methanol
Plant Gate	-	0.150	-	0.15
Distribution	-	0.030	-	0.03
Delivered Cost	$ 0.257	0.180	0.257	0.180
Federal Sales Tax	0.027	0.024	-	-
Federal Excise Tax	0.040	-	-	-
Provincial Sales Tax	0.095	0.095	-	-
Wholesale Cost	0.419	0.299	-	-
Retail Margin (7%)	0.031	0.021	0.031	0.021
Total Cost Per Litre	$ 0.450	$0.320	$0.288	$ 0.200
Total Fuel Consumption/Yr.	83,520 litre	192,096 litre	83,520 litre	192,096 litre
Total Cost/Vehicle/Yr.	$37,584	$61,470	$24,053	$38,419

It was assumed that a truck fleet of only ten vehicles would not be able to justify its own refuelling facility. A high proportion of fuel purchases would be made on the road at locations remote from the fleet depot. The diesel fuel price is therefore based on a retail pump price of 45 cents per litre, including retail margin and profit. The methanol fuel price is based on the COFA estimated gate price, which is explained in the paragraph referring to bus fuel costs, plus 2 cents per litre average national delivery cost by railway to a bulk central depot, and 1 cent per litre local distribution by truck. The retail margin and profit is taken as 7%, based on the November 1989 retail margin and profit for gasoline retail sales.

Table VII-3 summarizes the annual economic and financial costs per truck. Economic costs exclude taxes but include retail margin and profit. The table shows that the fleet operator would pay $24,000 per year more per vehicle (13 cents/km) to operate on methanol. The economic cost of methanol operation is 60% more than that of diesel. Methanol is less expensive than diesel per litre, but its lower energy content results in higher operating costs per kilometer.

C.2 Incremental Maintenance Costs:

Methanol engines are currently more complicated in construction than equivalent diesel engines. The extra components lead to increased maintenance requirements. Project MILE experience indicated several particular examples, notably glow plugs and fuel injectors. The sum total of long - term wear and component durability experience available is limited, and inhibits accurate prediction of associated servicing and repair needs. General engine reliability levels improved considerably during the course of the project. The maintenance costs incurred for project vehicles were very high in absolute terms due to the developmental state of the technology, and cannot be taken to represent expected costs for production engines.

The cost estimates used in this analysis are derived from consideration of the most persistent problems experienced with project engines, and the extent to which pre-production development may be expected to reduce or eliminate them. Considered on an engine type basis these problems were:

DDC 6V-92TA:

The injector tip holes become plugged with hard deposits derived from the engine lubricating oil. Maximum service life did not exceed 1000 hrs. A realistic average figure was around 500 hrs. Detroit Diesel expects to extend injector life by use of low - ash engine oils and a fuel additive, and has demonstrated good results during testing. The analysis assumes that diesel injectors last 10,000 hrs in a typical application, and that methanol injectors will achieve 4,000 hrs. This would equate to one year of service assuming an average bus speed of 15 km/hr, over 60,000 km/year. The DDC methanol injectors are not serviceable by a fleet and would simply be removed and replaced. The cost estimate for an exchange unit is $ 200. The annual cost of injector servicing is therefore estimated at:

6 x $200 = $1200 plus $100 labour,
total $1300.

The latest DDC engines use glow plugs only for cold starting and engine warm up. This is expected to greatly extend glow plug life. It is estimated that glow plugs will require replacing once per year on average at a cost of $300, including parts and labour.

A contingency allowance of $200 per year has been included to account for the added complexity and possible servicing requirements of the blower air bypass system.

Caterpillar 3406B

The injector life on the Caterpillar engines averaged approximately 1000 hours during the project. It is anticipated that a production engine would require injector replacement every 5,000 hours. This equates to once per year if the average truck speed is taken as 36 km/hr over 180,000 km/yr. The Caterpillar engine fuel injector nozzle is a simpler component than the DDC unit injector. The cost to fit 6 exchange units is estimated at $600 including labour.

The Caterpillar engines experienced a high rate of glow plug failure during the project. Average glow plug life was approximately 250 hrs. The glow plugs used were slightly modified versions of plugs designed for cold starting only. Caterpillar expects that durability would be greatly improved if it became economic to design and produce plugs for continuous service. This analysis estimates that all six glow plugs will have to be replaced at least 3 times each year at a total annual cost of $1500.

The valves and valve seats of the first project engine were unserviceable after 50,000km. A change of materials extended life to 100,000km. The wear was attributed to the lack of carbon from methanol combustion. In a diesel engine the free carbon particles provide some lubrication effect between the valve face and valve seat. As a consequence this analysis provides for adjustment of valve lash at 60,000km intervals, at an estimated cost of $300. Complete valve reconditioning is allowed for at 180,000 km. intervals, at a cost of $3,000 for a rebuilt cylinder head, and $2,000 for labour.

The MILE project Caterpillar engines were dismantled and inspected thoroughly by the factory at the end of project operations. The wear rate of major components, such as cylinder liners and crankshaft bearings, was no worse than for a diesel engine in the same type of service. A production methanol engine is therefore expected to have an equal service life to a diesel unit, and no provision is made for unusual major repairs other than valve reconditioning.

Table VII-4 summarizes the incremental operating and maintenance costs arising from the foregoing analysis.

D. INFRASTRUCTURE COSTS

Some extra costs may arise in adapting existing vehicle fuelling and servicing facilities to handle methanol. These include improved ventilation of indoor vehicle parking areas, higher capacity fuel pumps, fuel storage tanks and fire prevention equipment.

D.1 Maintenance and Parking Buildings

In Canada, buses are typically serviced and parked indoors because of climatic conditions. Service bays and parking garages may require additional ventilation to prevent accumulation of flammable methanol vapours that could result from accidental spills. Many transit properties already have high volume ventilation systems in the service and parking areas to remove engine exhaust fumes. We have estimated that possibly an additional $100,000 will be required to improve the ventilation in a facility dealing with 200 buses. Life expectancy of the equipment modifications is assumed to be 20 years. For amortization, a nominal interest rate of 12% is assumed as outlined previously.

The MILE project trucks were parked and serviced outdoors. Trucks are seldom stored indoors. Passenger comfort is not an issue, and a fleet normally aims to keep its vehicles out on the road at work rather than parked at the base depot. For the same reasons, there is usually no need to fuel trucks indoors. The analysis assumes that existing workshops and repair facilities have

Table VII-4. Incremental Annual Maintenance Costs

COST ELEMENT	BUS	TRUCK TRACTOR
Fuel Nozzles	1,300	600
Glow Plugs	300	1,500
Blower Bypass	300	-
Valves	-	5,600
Total Maintenance	$1,900	$7,700

sufficient ventilation because of the need to remove exhaust fumes when moving and testing vehicles. Additional ventilation in maintenance areas was not provided at any MILE fleets, but a number of fire and safety precautions were instituted which had a negligible effect on building capital costs.

D.2 Fuelling Facilities

This analysis assumes that the transit fleet will fuel from its own central fuelling facility, and the truck fleet will purchase fuel from retail outlets.

Most Canadian transit fleets of any size fuel and service their buses indoors. Methanol is classified as a flammable fuel, and is not currently approved for indoor fuelling. The analysis assumes $120,000 for construction of an outdoor fuelling facility to accommodate 200 vehicles, fuelling at a rate of 12 vehicles per hour. Carbon steel underground tanks with cathodic protection would be used, similar to diesel or gasoline. Methanol is stored in carbon steel tanks at manufacturing plants. The life span of the underground tanks is expected to be 15 years.

For the truck operation, it is assumed that the retailer's margin and profit on fuel sales includes the cost of methanol fuelling equipment and underground tanks.

Table VII-5 outlines the expected incremental capital costs for the changes to be made to the fleet infrastructure.

E. TOTAL INCREMENTAL COSTS

The total annual incremental costs for the hypothetical bus and truck fleets are summarized in Table VII-6. The extra financial cost to the bus fleet is $7,672 per vehicle per year for methanol operation. The economic cost increment is $10,985 per vehicle per year. Fuel cost has the biggest impact on the differentials. It accounts for 45% of the economic cost differential and 62% of the financial cost differential. Infrastructure costs are a very minor component at $110 per vehicle per annum, or approximately 1.5% of the financial cost.

The incremental costs for the truck fleet study are much higher, primarily because of the larger amount of fuel

Table VII-5. Incremental Infrastructure Costs

	Bus	Truck
Parking and Maintenance Facility		
- additional capital	100,000	-
- annualized capital	9,148	
Fuelling Facility		
- additional capital	120,000	- part of retail margin
- annualized capital	12,844	
TOTAL		
- additional capital	$220,000	-
- annualized	$21,992	-
Annual Amortized Cost Per Vehicle	$ 110	- part of retail margin

Table VII-6. Summary of Annual Incremental Costs
(Per Vehicle)

Item	Bus		Truck	
Engine and Vehicle	$2,205		$ 707	
Annual Maintenance	$1,900		$7,700	
Infrastructure	$ 110		NA	
	Economic	Financial	Economic	Financial
Incremental Methanol Fuel	$6,770	$3,457	$14,366	$23,885
Total Incremental Methanol Costs	$10,985	$7,672	$22,773	$32,293

consumed. The economic increment is $22,773 per truck per year, and the financial increment is $32,293 per truck per year. Methanol fuel cost represents 63% of the economic increment, and 74% of the financial increment.

The other major cost item is the anticipated maintenance cost, assumed to be $7,700 per annum. Valve seat renewal comprises over 70% of this figure.

Table VII-6 illustrates that fuel costs are the major influence on cost differentials in comparison to diesel. The basic delivered cost of methanol, on a per litre basis (Tables VII-2 and VII-3) is less than that of diesel fuel, but this advantage is totally negated by the greater volume of methanol required.

Methanol Fuel Price Sensitivity:

Because the price of methanol was shown to be such a dominating factor in the incremental cost assessment, sensitivity analysis was performed to assess the impact of adjustments in the prices of methanol and diesel. Three cases were considered:

- Methanol produced specifically for the transportation fuel market;
- Higher cost low-sulphur diesel fuel;
- Changes in crude oil price;

The sensitivity analysis examines economic costs only, so eliminating any distortion introduced by taxation inconsistencies. It is expected that in the long term, fuels should be taxed equally on an energy content basis.

Methanol is currently produced to stringent purity specifications for sale to the chemical industry. It is transported by rail car or truck. In Canada, the largest batch quantities are moved in unit train loads from the producing plant to shipping quays for overseas export. Methanol fuel prices would drop if a large scale methanol plant were available specifically to serve the fuel market. The Canadian Oxygenated Fuels Association (COFA) has proposed a 10,000 metric tonne per day (mtd) methanol fuel plant located in Edmonton to supply markets in Canada and California. Natural gas feedstock would be piped directly in from surrounding gas fields. The plant would be linked to the planned major markets by a pipeline. Fuel methanol could be produced to a less exacting and less costly specification, and the cost of pipeline transportation would be well below that of the current rail and road modes. The two factors would result in a significant drop in fuel methanol costs to vehicle fleets.[5] The fuel methanol cost at the plant gate is estimated to be $0.10 per litre. Distribution costs, for pipeline transfer to a central depot and local delivery by truck, are assessed at $0.02 per litre in Winnipeg and $0.01 per litre in Vancouver. Hence the overall delivered fuel cost (before tax) is $0.12 per litre in Winnipeg and $0.11 per litre in Vancouver.

The costs of diesel engines and diesel fuel will both increase significantly in the future. Engine manufacturers are actively pursuing the use of particulate traps and other engine modifications to meet the 1991 and 1994 U.S. standards. Low sulphur fuel (less than 0.05%) will definitely be required for sulphate emissions reduction. The Petroleum Institute for the Conservation of the Environment (PACE) has estimated that retail diesel fuel prices in Canada will increase by an average of 3 cents per litre. Fuel consumption may also increase by as much as 6%. The cost of a particulate trap is estimated at $5,000, based on discussions with potential manufacturers.

Table VII-7 outlines the impact of these changes.

The annual incremental cost of methanol operation for the bus fleet is reduced from $10,985 to $3,734 per vehicle, giving a new total cost of $747,000 for a 200 bus fleet. This represents a 66% reduction in before-tax annual operating costs. Under these conditions the methanol fuel cost increment drops to $343 per vehicle, or 9% of the total incremental cost. Incremental costs attributable to methanol bus engine maintenance account for $1,900, or 51% of the total incremental cost.

In the case of the truck fleet the cost of methanol fuel is $5,486 less than the cost of diesel. However, the fuel cost saving is not sufficient to offset the higher capital and maintenance costs. When all incremental costs are considered methanol truck operation results in an incremental cost of

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[5] "Cost Effectiveness of Alternative Transportation Fuels in Urban Bus Operations." Report for: Energy, Mines and Resources Canada. SYPHER:MUELLER International Inc. November, 1989.

Table VII-7. Fuel Price Sensitivity
($/Litre Unless Otherwise Noted)

Cost Elements	Bus		Truck	
	Methanol	Diesel	Methanol	Diesel
Fuel Cost, Plant Gate	0.10	-	0.10	-
Distribution	0.02	-	0.01	-
Delivered Cost	0.12		0.11	
Retail Mark up	-	-	0.008	0.015
Total Cost	0.12	0.25	0.118	0.318
Yearly Consumption(Litres)	71,760	33,072	192,096	88,531
Total Fuel Costs($)	8,611	8,268	22,667	28,153
Incremental Methanol Cost($)	343		(5,486)	
Other Incremental Costs($)	4,215(1)	824(2)	8,407(1)	1,332(2)
Net Incremental Costs($)	3,391		7,075	
Total Incremental Costs($)	3,734		1,589	

Notes: ( ) denotes a cost saving

1. Engine, vehicle, maintenance and infrastructure for methanol.
2. Amortized capital cost of particulate trap.

$1,589 per truck per year. When the fuel cost differential is reduced the methanol engine maintenance costs become the overriding consideration. If methanol engines are to successfully penetrate the market place they will have to offer higher overall reliability, and maintenance costs competitive with diesels. This is not an impossible target, but it will take some time to achieve and demonstrate convincingly to potential users who expect, and get, at least 500,000km trouble free operation from a diesel engine.

There have also been discussions concerning the imposition of aromatic standards on diesel fuel, which is being considered in California. This could result in an average price increase of 10 cents per litre. However, at this time, only California has adopted this route. The E.P.A. has no intentions to adopt an aromatic content standard and Canada has yet to adopt "clean diesel" standards. The impact of low aromatics is not addressed here but would make methanol much more competitive relative to diesel.

Crude Oil Price Sensitivity:

The current cost of crude oil is approximately $19 (U.S.) per barrel. The pretax cost of diesel is assumed to be $0.220 per litre for the bus fleet and $0.257 per litre for the truck fleet.

- The pre-tax diesel price required to offset all additional costs associated with methanol usage.

For the purposes of this comparison, methanol costs are assumed to remain constant.

Table VII-8. Crude Oil Price Sensitivity
[Per Vehicle Basis Unless Otherwise Noted]

Item	Bus	Truck
Methanol Fuel Cost	$ 13,634	$ 38,419
Total Diesel Consumption (litres)	31,200	83,500
Equal Cost Diesel Price (Fuel Only)	$ 0.44	$ 0.46
Equivalent Crude Oil Price ($ U.S.)	$ 32.6	$ 34.3
Total Incremental Methanol Cost	$ 17,849	$ 46,826
Equal Cost Diesel Price (Total)	$ 0.57	$ 0.56
Equivalent Crude Oil Price ($ U.S.)	$ 42.2	$ 41.4
Future Methanol Fuel Cost	$ 8,611	$ 22,667
Total Cost Assuming:		
- Future Methanol Cost and		
- No Extra Valve Servicing Cost	$ 12,002	$ 24,142
Equal Cost Diesel Price (Future Case)	$ 0.36	$ 0.27
Equivalent Crude Oil Price ($ U.S.)	$ 26.9	$ 20.0

Note: Fuel Costs exclude taxes.

This analysis investigates:

- The pre-tax diesel price required to offset methanol fuel costs only.

Table VII-8 shows the results of the analysis. The total annual methanol fuel costs per vehicle, and the total annual diesel fuel consumption per vehicle, are derived from tables VII-2 and VII-3. The diesel cost for equal fuel pricing is then calculated by dividing the quantity of diesel into the methanol price.

The calculation shows that, in the case of the bus fleet, the pretax cost of diesel fuel in Manitoba would have to rise by 100%, from $0.22 per litre to $0.44 per litre, to offset the increased methanol fuel cost alone. To offset the total cost of methanol operation, the diesel price would have to increase by 160% to $0.57 per litre before taxes. Assuming a linear relationship between the delivered cost of diesel and the cost of crude oil, these price increases would translate into crude oil prices of $33 and $42 (U.S.) per barrel.

In the case of the truck fleet, the analysis shows that the cost of diesel would have to rise to $0.46 per litre to offset the increased cost of methanol fuel alone. This is a 79% increase in the assumed base price of $0.257 per litre. It is equivalent to a cost of $34 (U.S) per barrel of crude oil. Diesel fuel costs would have to rise an additional $0.10 per litre, to $0.56 per litre, to entirely offset all methanol related costs. This is equivalent to a price of $41 (U.S) per barrel of crude. Almost 70% of the $8,400 in non-fuel methanol costs is attributable to valve seat renewal work. Assuming that valve seat problems could be overcome, total incremental costs could be reduced by $5,600. Diesel fuel would then have to cost $0.49 per litre (before taxes) in order to offset all methanol related costs.

When lower methanol fuel costs associated with a 10,000 mtd methanol plant are considered along with clean diesel technology, methanol breaks even with diesel at crude oil prices of $27 for buses, and $20 for trucks, when all incremental cost factors are considered. For the trucks, it is assumed that valve problems will be corrected by improved engine design.

F. EMISSIONS BENEFITS

F.1 Emissions Profiles of Emerging Technology:

This analysis examines emissions from a methanol powered DDC 6V-92TA engine. This analysis assumes that a production version methanol engine that meets 1991 U.S. emissions standards will be available. Canada has not legislated more stringent emissions standards than those in effect since 1988. However this analysis assumes that any future Canadian emissions regulations will follow those in the U.S. Table VII-9 depicts 1988 Canadian emissions regulations and the pending 1991 U.S. emissions regulations along with the DDC methanol engine emissions profile. Engines destined for urban buses will be subject to a 0.13 gm/KW-hr particulate standard whereas truck engines will face a 0.34 gm/KW-hr standard.

Detroit Diesel, a major supplier to the North American urban transit market, has already made a commitment to produce a methanol powered production engine that meets U.S. 1991 urban bus standards. DDC has released data that shows their methanol engine presently meets the 1991 bus engine standard. Caterpillar, a major supplier to the truck market, has not made any official commitment regarding their future plans for methanol engines. Stringent rules for U.S. truck engines will not take effect until 1994.

F.2 Vehicle Emissions Profiles:

Heavy duty engine emissions are reported on a specific weight basis (g/MJ in Canada) in order to ascertain engine compliance with federal standards. The emissions are based on an emissions test meant to replicate torque versus engine RPM over a mixture of highway and urban driving. However, the cycle does not discriminate on the type of application, i.e.,

Table VII-9. Emissions Profiles

	EMISSIONS CONSTITUENT HC[1]	CO	NOx	PM	ALD[2]
	Unit: g/KW hr (= 0.746 g/bhp hr)				
EMISSIONS STANDARDS					
1988 CANADA	1.7	20.8	8.0	0.8	NA
1991 U.S.A. (urban buses)	1.7	20.8	6.7	0.13	NA
METHANOL ENGINE					
DDC 6V-92TA	1.47	2.25	3.08	0.11	0.16

Notes:

1. Beginning in 1991, the HC component of emissions from methanol powered engines in the U.S. will be termed OMHCE (organic mass hydrocarbon equivalent). OMHCE measure is defined as: Mass of HC + 0.433 mass of methanol + 0.462 mass of formaldehyde.

2. Aldehyde emissions are not directly regulated by the E.P.A. Their inclusion is for information purposes only.

urban bus or intercity truck. The emissions factor methodology[6] was used to predict on road emissions in terms of mass of emissions per unit distance travelled (gm/Km). An emissions factor (EF) is a function of fuel density (FD), specific fuel consumption (SFC) and vehicle fuel consumption (VFC).

EF= FD/(SFC*VFC)

where: EF is in units of KW-hr/Km
FD is in units gm/Litre
SFC is in units of gm/KW-hr
VFC is in units of Km/Litre

The emissions factor is then used to convert engine dynamometer emissions results to a weight per distance value:

i.e.,$\text{Emission}_i = \text{EF} * \text{BSEmission}_i$

where: Emission_i is the emissions constituent "i" in gm/km

BSEmission_i is the brake specific emissions of constituent "i" recorded on an engine dynamometer

Table VII-10 presents an emission factor derived for the DDC engine and an emissions factor projected for a 1991 model diesel bus engine[7]. The emissions factors can be used to predict vehicle emissions profiles. The 1991 emissions regulation was selected as a point of comparison of specific emissions for both engines since a true comparison between a 1991 model diesel and methanol engine is not possible. With

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[6] Smith, M.C. IV (U.S.E.P.A); Technical Report-Heavy Duty Vehicle Emission Conversion Factors 1962-1997. Report number EPA-AA-SDSB-84-1. August 1984

[7] Smith, M.C. IV; op cit

Table VII-10. List of Emissions Factors

Engine Type	Emissions Factor [kw hr/km]
DDC 6V92TA Methanol Engine	1.80
"Typical" 1991 Diesel Bus Engine	1.76

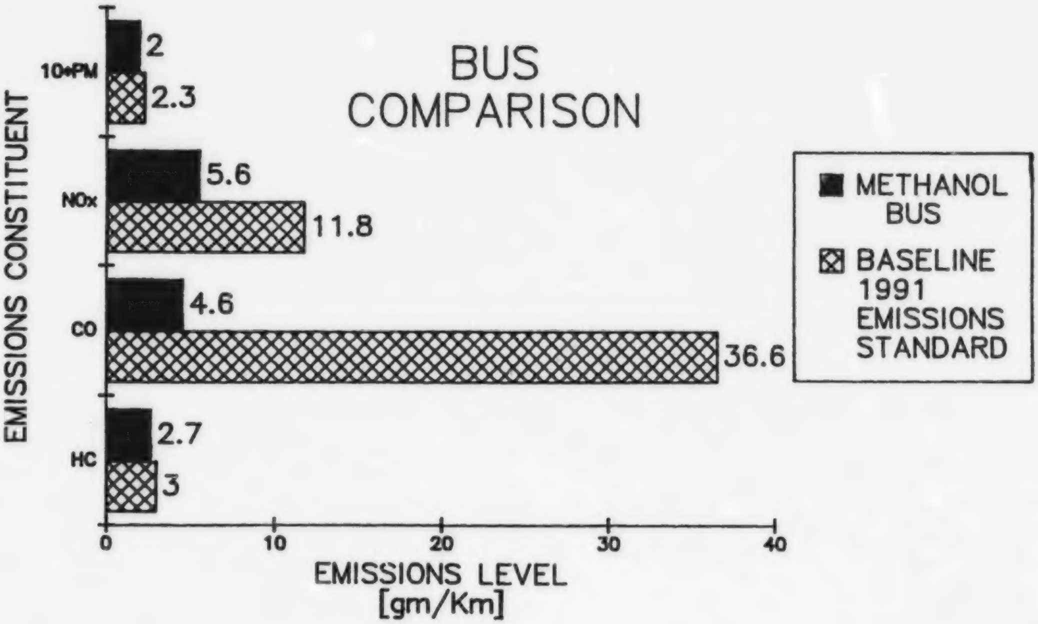

Figure VII-1. Vehicle Emissions Profiles

the exception of DDC, engine manufacturers have not revealed their specific product for transit, and associated emissions levels for 1991. Some manufacturers may not be able to meet the pending regulations.

Therefore, a comparison of methanol engine emissions to the emissions standard will help quantify the benefit afforded by a methanol engine with respect to the intended regulation. Ultimately, any engine offered for sale in model year 1991 and beyond will have to at least meet the proposed standard.

Figure VII-1 illustrates the on road emissions profile for a methanol bus fleet compared to the baseline 1991 diesel standard. The emissions profile for the 1991 baseline diesel was derived using the 1991 urban bus emissions standard and emissions factor.

The methanol powered vehicles produces lower quantities of all regulated emissions on a per kilometre basis compared to the baseline diesel emissions profile. Of interest is the fact that there is a wide margin between diesel and methanol vehicle emissions for CO and NOx.

The methanol bus produces 87% less CO and 53% less NOx on a gm/Km basis than required by the standard. Reductions in NOx emissions will ultimately reduce ozone formation. The difference between HC and particulate emissions from diesel and methanol engines is quite slim. There is only a 0.3 gm/km difference (corresponding to a 10% difference) in HC emissions and a 0.03 gm/kw difference (corresponding to a 13% difference) in particulate emissions. Nevertheless, the engine still meets the emissions standard and procedures a net reduction in regulated emissions.

F.3 Qualitative Benefits:

Methanol engine technology offers a viable means to readily meet the more stringent particulate standards. Methanol effectively burns soot free.

Particulate matter is made up of solid or liquid matter containing a solid carbonaceous core (elemental carbon) upon which is absorbed a mixture of soluble organic fraction (SOF), sulfates, oxides and trace elements[8,9]. Concern over diesel particulates center on particle size and composition. Diesel particulates tend to be a localized problem. Emissions are distributed around their source and tend to rapidly settle out of the air, soiling the surrounding area.

Diesel particulates are easily inhalable because of their size. Once settled into the lungs, they can decrease respiratory efficiency. Particulate composition can also pose a serious health hazard. The SOF portion of particulate consists of the unburned portion of HC's from lube oil and fuel. Certain constituents within the SOF portion of particulate, such as polyaromatic hydrocarbons, are suspected carcinogens. Diesel particulate has been estimated to account for approximately 11% of all California state wide cancer cases attributable to motor vehicles[10]. Thus, methanol engines have the potential to reduce serious problems through reduced particulate emissions compared with existing diesel engines.

The hydrocarbon (HC) portion of exhaust emissions contains a mixture of different hydrocarbon constituents. The actual make up is entirely dependent on the fuel type and engine model. There is concern over the hydrocarbon portion of exhaust emissions since certain HC constituents react with nitrogen oxides and ultra violet radiation to produce photochemical smog, also referred to as ozone (The actual mechanism of smog formation is quite complex). To maintain consistency with U.S. Federal Regulations covering methanol in motor vehicles, HC emissions can be categorized according to their photochemical reactivity as:

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[8] National Research Council; Diesel Technology, Impacts of Diesel Powered Light Duty Vehicles. National Academy Press, Washington, D.C. 1982

[9] Richards, R.R., et al (Caterpillar Inc.); Diesel Engine Emissions Control for the 1990's. SAE paper # 880346

[10] State of California Air Resources Board; Motor Vehicle Toxics: Assessment of Sources, Potential Risks and Control Measures. Mobile Source Division. No report number. June 1989.

- oxygenated HC's - least reactive;
- non-oxygenated HC's - moderately reactive; and
- aldehydes - most reactive.

However, there are certain exceptions to these broad categories. For example, methane gas, CH_4, is a non-reactive HC, but conversely, it is a green house gas.

The total hydrocarbon level reported for the DDC methanol engine meets the 1991 emissions standard. There have been concerns about aldehyde emissions from a methanol engine. The major constituent of aldehyde emissions is formaldehyde which is a suspected carcinogen. Methanol engines produce greater aldehyde emissions than a comparable diesel engine. However, the total HC measurement, reported as organic mass hydrocarbon equivalent (OMHCE), already accounts for the photochemical reactivity of all HC components (i.e., aldehydes, non-oxygenated and oxygenated hydrocarbons). The total HC level for the methanol engine is directly comparable to the HC number reported from diesels. Thus HC emissions from methanol engines pose no greater ozone forming propensity than a corresponding diesel.

Nitrogen oxide (NO_x) emissions pose a number of problems. As was previously mentioned, NO_x emissions react with HC's to form tropospheric ozone, or smog. Increased levels of tropospheric ozone have been associated with decreased agricultural crop yields, declining forest growth and an increased hazard to human health. Ozone can aggravate respitory disease, lead to chest discomfort and weaken the immune system. NO_x by itself poses a health and environmental problem. Inhalation of NO_x at concentrations as low as 0.3 ppm can lead to respitory problems. A build-up of nitrogen dioxide (NO_2) gas in a region will result in a brownish haze which can impede visibility. NO_x can also be precipitated out of the atmosphere as acid rain.

Methanol engines offer an excellent opportunity for engine manufacturers to achieve both NO_x and particulate control. Historically, diesel engine designers have had to tradeoff NO_x control at the expense of particulate control. Methanol powered engines, as illustrated in Chapter 5, offer major reductions in both particulates (75%) and NO_x (55%).

Carbon monoxide (CO) is a result of incomplete combustion. CO poses a health concern and for this reason, tailpipe emissions have been regulated. CO is a colorless and odourless gas that can displace oxygen in the blood resulting in asphyxiation. Gasoline (Otto cycle) engines have historically been the primary source of CO emissions. Emissions projections show a gradual decrease in CO emissions from motor vehicles in Canada due to more stringent emissions regulations[11]. Although methanol engines typically produce greater amounts of CO than their diesel counterparts, they are still well within current regulatory standards. The DDC methanol engine is an excellent example of a methanol engine that successfully employs catalyst technology to achieve significant reductions in CO (and HC) emissions compared to earlier versions of the engine[12].

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[11] Transport Canada and Environment Canada; A Plan To Identify and Assess Emission Reduction Opportunities From Transportation, Industrial Engines and Motor Fuels. Report # TP 9773E. May, 1989

[12] Project MILE steering Committee notes. Dec. 1989

G. SUMMARY AND CONCLUSIONS

With existing fuel prices and engine technology, methanol cannot be considered cost competitive with diesel engines. Methanol fuel costs are the single largest component of the extra costs for methanol in large engines. However, methanol is currently produced for chemical markets. A more likely scenario would be methanol plants built specifically for the transportation market, with pipeline distribution to major markets. Furthermore, it is likely that the cost of using diesel technology will increase to meet new emissions standards. Under this scenario, methanol is economically competitive at crude oil prices of $20 to $27 U.S. per barrel depending on bus or truck application.

Methanol promises definite environmental benefits. Methanol engines have been shown to meet the stringent 1991 regulations for bus applications. It is not clear or certain that diesel engines will be able to meet these standards. Not only do methanol engines meet the standards but they also significantly reduce nitrous oxides and particulate emissions, relative to the standard and today's diesel engines. Nitrous oxides are a major constituent of urban smog and ozone. Vehicle particulates have been directly linked to cancer and human respiratory diseases.

Methanol engines with the use of a catalyst can produce significant reductions in carbon monoxide emissions compared with the regulations. Carbon monoxide can lead to asphyxiation.

CHAPTER VIII: BARRIERS TO COMMERCIALIZATION OF METHANOL

A. INTRODUCTION

It is obvious that methanol cannot become a viable fuel for Canadian fleets if methanol engines and vehicles are unreliable, lacking in performance or unreasonably costly to fuel. It is equally true, but less often stated, that methanol will not be adopted if potential users are unaware of its existence or its capabilities, or if their perceptions of methanol as a fuel are muddled or erroneous.

Project MILE recognized that methanol would have to overcome this particular barrier if it was ever to be accepted for fleet use. In order to assess the extent of the problem, two surveys were conducted, in which fleet managers and owners were asked a series of questions designed to examine their depth of knowledge and attitudes regarding methanol as a fuel. The first survey was taken in mid 1986, before project vehicle operations began. The same group of people was surveyed again at the end of 1989. The results of the two surveys were compared in order to see if the project progress and results had had any effect on the level of knowledge and attitudes of the sample group.

B. OBJECTIVES

The objectives of this survey were:

- To determine, at the outset of the MILE Project, those factors which would affect fleet managers' decisions to consider methanol as an alternative fuel.
- To determine, at the completion of the methanol Project, the impact the MILE Project had on fleet manager's knowledge of and attitudes toward methanol.

The overall goal for the fleet manager study was to assess the attitudes of the key decision-makers regarding the financial and operational feasibility of methanol for bus/truck fleet operations.

C. SELECTION OF FLEETS

The Managers of fleets participating in the MILE Project were surveyed including Winnipeg Transit, Medicine Hat Transit, and Williams Moving and Storage.

A cross-section of other fleets was chosen to represent diesel fleets across Canada. Altogether twenty fleets in Ottawa, Winnipeg, Medicine Hat, Calgary and Vancouver were surveyed. These fleets were engaged in many different types of transportation activities, and were of widely varying size.

D. DELIVERY OF SURVEY

Efforts were made to ensure that the people surveyed were actually responsible for purchasing decisions and authorized to buy vehicles and engines. Usually the person surveyed was the company president or, in larger organizations, the manager of operations or maintenance. The survey was conducted in person.

E. SURVEY RESULTS

The results of the two surveys are summarized in sections F to H. The survey results have been identified as "barriers" (although they were not dealt with as such during the survey).

F. TECHNICAL BARRIERS

F.1 Engine Complexity

The first and second surveys showed no appreciable difference in respondents' answers regarding complexity of methanol engines versus diesel engines. In both surveys, 67% to 70% of respondents felt that a methanol engine would be more complex in construction. Managers familiar with methanol engines through involvement in MILE understood the intricacies of various manufacturers' methanol engines and how they were different from the diesels. These same people recognized that the basic engine block and cylinder head assemblies were virtually identical; the differences were in the fueling arrangements. Most of the respondents were familiar with engine technology, and the concept of an engine running on an alternative fuel was of no particular concern. Nobody thought that a methanol engine would be less complex than a diesel engine.

F.2 Engine Performance

In both surveys, all respondents were very satisfied with the performance levels obtained from diesel engines. The one fleet manager who had experience with a compressed natural gas engine in one of his vehicles was equally pleased with its performance. The percentage of managers who felt that a methanol engine would be inferior to a diesel engine dropped from 67% to only 54%. During the initial survey, not one manager felt that methanol engines would perform as satisfactorily as diesel engines.

This view changed markedly in the final survey, where 39% of the managers felt that the methanol engines would be superior in performance. There was no actual reasoning behind the changed perception; it was more of a "general feeling" and news of demonstrations being filtered throughout various industry publications and discussions at conferences, etc. Unique to these latter figures were the responses from the three managers who had personally experienced the use of methanol engines. Only one of the managers felt that methanol engine performance was superior to the diesel engines in the remainder of his fleet; the other two managers, based upon some rather poor reliability levels in the initial stages of their demonstration programs, felt that the methanol engines had delivered inferior levels of performance.

Several managers referred to their propane experience. Three managers stated that a major reason they discontinued the use of propane vehicles was poor performance. They felt that the engines did not perform properly and mentioned specifically the failures of propane engines to start in very cold weather, and the lack of power during operation. The most vehement comment on engine performance was delivered by a manager who had experience with propane engines. The engines had not met expectations at any time and he had discontinued their use.

F.3 Engine Maintenance

There was no substantial change in managers' reactions to engine maintenance costs. In both surveys, 50% to 57% of the respondents felt that the methanol engines would be as easy to repair as the diesel engines. One respondent felt that, because methanol is not as good a lubricant as diesel, there would be more wear on the valve seats. Initially, 50% felt the methanol engines would be more difficult to repair while, in the final survey, this number declined marginally to 42%. In both surveys, no manager felt that a methanol engine would be easier to repair. As for the maintenance costs, initially 67% felt that the methanol engines would be more costly; this number dropped slightly to 54% in the final survey. Only one manager who had actual experience with methanol engines indicated that the ease of repairs would be the same; the two other managers with experience indicated that the actual maintenance costs would be worse.

F.4 Engine Reliability

The respondents were asked how important engine reliability was to their decision in vehicle selection. In 19 cases out of 20 they ranked the characteristic as "very important". This was the only characteristic which virtually all respondents felt was critical to their operation. The manager of an inter-city bus line commented that, when you have a load of paying passengers, it is critical to have a reliable engine. The manager of a moving company commented that, with a shipment of goods to Vancouver and a delivery deadline, engine reliability is essential. The manager of a farm stated that, with very short periods of time for putting in and taking off crops, engine reliability is of utmost importance. The fleet managers were willing to compromise vehicle purchase price in return for better reliability. The managers of two moving companies had recently purchased Mercedes-Benz vehicles because the quality of the engine was perceived to be superior.

Between the first and second surveys a number of changes in the transportation industry took place, particularly in the highway trucking sector. Profits margins narrowed and all managers were attempting to forecast what impact such items as free trade, deregulation and fuel costs would have on their market share. To ensure minimal costs and fleet down time, they were looking for maximum engine reliability. This was also true for the passenger carriers, both urban transit and highway bus.

F.5 Outdoor Parking

The first survey indicated that outdoor parking of vehicles with methanol engines could be inconvenient for some fleet. The two city transit bus companies and the intercity bus company surveyed started their buses in indoor garages, and would be reluctant to change to outdoor storage. All three managers stated that too much time is required to warm the interior of a bus in winter when it is stored outdoors, and drivers and passengers complain if the bus is cold. It is anticipated that methanol vehicles could be parked indoors or outdoors equally safely, based on experience with gasoline vehicles.

In the case of the three MILE project fleets, the two urban transit facilities depended on storing vehicles indoors. Neither had had any problems with storing the methanol vehicles indoors. No special arrangements were made to have the vehicles segregated from the diesel fleet. No special signs were made to advise personnel that the vehicles had methanol engines. The same practices were employed at both facilities. The exception was in the mechanical servicing areas, where one transit facilityused special signs that indicated NO SMOKING in the area around the bus.

For truck fleets outdoor parking was normal and the use of methanol engines did not present a parking problem.

F.6 Outdoor Refueling

The only managers who required indoor fueling as a normal practice were from an urban transit system and a highway bus firm. These two organizations had used indoor fueling for many years with diesel buses, because of climatic conditions. In one case, all of the company's vehicles were put through an "assembly line" where fuel was dispensed, engine and transmission lubricants checked, interiors cleaned and exteriors washed. In the other case vehicles were stored indoors at all times and all maintenance work was performed indoors, including fueling. One other transit facility had fueled propane vehicles outdoors, but had constructed a small shelter to protect servicing crews from the weather. In all other organizations outdoor fueling with diesel was the norm. Outdoor fueling with methanol would present a problem to most large transit bus fleets.

Fleet locations included the Pacific coast of British Columbia, Calgary, Medicine Hat, Winnipeg and Ottawa. Several of the firms operated vehicles in northern Alberta, British Columbia and, in two cases, Alaska and the Arctic.

F.7 Cold Weather Starting

All fleet managers were familiar with the problems of starting diesel engines in cold weather. In the initial survey, 60% of the managers felt that methanol engines would be superior to diesel engines in terms of cold weather starting. However, in the final survey, this number had dropped to only 46%. 20% of the managers in the first survey felt that the methanol engines would be inferior; this number rose to 39% in the final survey. One of the underlying reasons for this change in perception was due to industry interchange about propane engines' starting abilities and the confusion generated throughout the industry about alternative fueled engines as a whole.

F.8 Range

Methanol has approximately half the energy value of diesel, and so operators must refuel twice as often with the same size of fuel tank. An alternative is to increase tank capacity but this increases gross vehicle weight. This was not acceptable to all managers. During the first survey, all respondents indicated that they did not want to refuel more often that at present. Some of the managers indicated that more frequent refueling costs drivers time and, therefore, money. In the second survey, 85% felt that additional refueling would be an inconvenience. One particular firm had fleet operations in a true Arctic environment. Fuel was supplied through a contractual arrangement with the customer. More frequent fuelling, however, was not perceived as a problem. Another firm, under the impression that methanol would be available at retail outlets along the routes covered, did not have a concern with additional refueling.

Additional refueling did present a major problem for the transit bus firms. Buses are taken out early in the morning and must carry enough fuel to complete their routes. Refueling of all buses was conducted only once a day and the operation was "assembly line". With hundreds of buses travelling through this line each day, it would be a major inconvenience to have some buses coming back to the garage at odd intervals to be refuelled.

F.9 Vehicle Weight

Most managers in the first survey did not want to compromise payload capacity by the addition of extra fuel tanks. In the second survey only 50% of the managers felt the additional weight of fuel carried would be a concern. Many of the trucking firms were buying lighter tractor and trailer combinations to maximize payload while remaining within the gross weight permitted on the highway. In several cases every extra kilogram of fuel carried meant an equal reduction in payload capacity. For other trucking firms, particularly those that specialized in moving furniture, household goods and large manufactured items, weight was not as critical as the volume of cargo space available. Therefore, additional tankage (within reason) would not be a problem. For highway buses the primary concern was space available for passengers primarily and cargo secondarily. Additional tankage was not expected to cause problems because of extra weight or loss of cargo space.

F.10 Similarity Of Engines In Fleet

The fleet managers were asked how important it was to have all the same type of engines in their fleet. One company bought new trucks and sold them within three years, before major maintenance was required. For this company, another type of engine was not a problem. Two other companies contracted out all maintenance work and currently operated several different types of engines without difficulty. One intercity bus company did all the maintenance of its own vehicles, and tended to keep the vehicles for several years. Introducing new engines into the fleet was an important consideration because it would mean an additional inventory of spare parts. The manager added that, while it was an important consideration, it would not stop him from trying a new engine if there were other benefits. For the majority, having the same types of engines was a very important factor. Frequently the question was answered in one of two ways, on the basis of fuel used, or by engine manufacturer. Some of the managers wanted only one engine manufacturer's product and only diesel fuel. Their loyalty to one manufacturer was based upon personal experience as well as industry comments about reliability, past performance, service, etc. Others were not adverse to using a mix of engine makes but were adverse to using a fuel other than diesel. Other managers were not adverse to using various engine types and would consider using other fuels, dependent upon the benefits to be derived in doing so.

F.11 Using Two Types Of Fuel

Fifty-seven percent of respondents in the initial survey felt that using two types of fuel would not be a problem. Some had gone through the process of changing from gasoline to diesel; some had a combination of diesel and propane (or methanol) in use, and one firm had vehicles using diesel, gasoline and compressed natural gas. In the second survey, only 29% of the respondents thought that using a fuel other than, or in addition to, diesel would be a major concern. One particular company was using kerosene instead of diesel fuel for arctic operations. The engines were apparently performing well on this "alternative" fuel. Kerosene was used because it did not solidify in severe winter months. Only one facility, a transit operation, indicated that two types of fuel (one of which required outdoor fueling) would present a problem. The primary concern was the inconvenience of having to fuel some vehicles outdoors.

F.12 Mechanics Of Conversion

Initially, only 25% of fleet managers said they would consider converting existing engines to operate on methanol, and only with major government incentives. In the final survey, this number had increased to 65%; but with the same provision. Even with governmental funding they would expect to see actual incentives for converting their engines. Many managers indicated that they were personally aware of or had experienced first-hand conversions from gasoline to propane or compressed natural gas. The conversion process was obviously not insurmountable; but government funding had been required. Managers felt that they could clearly see the results from "someone else taking the chance" of conversion work. One particular transit facility had experienced many problems through taking a diesel engine and trying to retrofit it to methanol configuration. It was clearly in favor of using methanol engines, but engines built in a factory as a production item into a vehicle chassis also specifically designed for methanol fuel.

F.13 Fuel Availability

Lack of methanol fuel at retail outlets would be a major technical barrier. In the first survey, only three fleets refueled at their own central refueling facility. This number did not change appreciably in the final survey. 85% of the respondents indicated that fuel availability at retail outlets was an absolute necessity. The trucking firms all required fuel availability on a continent-wide basis due to the extent of their operations. The highway bus carriers had a similar need, but frequently used contractual arrangements with other bus carriers for fuel and servicing throughout Canada and the U.S. They indicated that if the other firms providing fuel could not obtain an alternative fuel, they could not possibly consider using other than diesel. The only firms that did not have a major concern were the city transit operators. Their vehicles returned, either at the end of a shift or the end of a day, to a central refuelling area. Vehicles did not leave the urban area at any time and therefore availability of an alternative fuel was limited only by the delivery schedule of the fuel supplier.

G. ECONOMIC BARRIERS

G.1 Labour Specialization

During the first survey all managers recognized that the specialized nature of methanol engines would probably require additional training for their service personnel. In the second survey this perception had not changed appreciably. Service personnel were generally involved in regularly scheduled work such as oil changes, in-frame engine replacements and brake repairs. Work of a major nature, such as an engine or transmission rebuild, was normally put out to a specialist workshop. Therefore training for mechanics was not seen as a major drawback to using methanol fuel. Those firms that did do their own rebuilding work and diagnosing and rectifying of problems thought that their staff were fully capable of handling new technology. Some gave, as an example, the advent of computerized engines and solid state components. In the two transit facilities using methanol engines staff had received training from the engine manufacturer. As a result one fleet had not needed the engine manufacturer's local service representatives for over one year.

G.2 Capital Cost

During the initial survey it was understood that methanol engines would be appreciably higher in cost than their diesel counterparts. Three years later this was still true. In both surveys virtually all managers felt that, while the capital cost of an engine was important, there were other factors that were equally or more important. Items listed by the managers included engine reliability, parts availability, warranties and emissions. One firm felt that the warranty from the engine manufacturer was the most important factor. The initial cost of an engine might be better from one supplier but the saving could mean a shorter warranty period or fewer items covered. A transit operator mentioned that the need for minimized emissions and black smoke was a definite requirement for operating personnel. It also affected the public perception of how his company was being a good corporate citizen with respect to the environment.

G.3 Maintenance

Engine reliability was definitely the primary requirement of all managers in both surveys. Maintenance, cost of repairs and the availability of parts ranked a clear second in terms of engine purchasing decisions. These three items were inseparable to all fleet managers in both surveys. The engines had to be readily repairable, down time for repairs had to be minimal and parts had to be obtainable at a moments' notice. The trucking industry expected parts availability on a North American wide basis. Managers could not tolerate a tractor trailer unit in for repairs thousands of miles from home base waiting for parts from the manufacturer or supplier. All the managers said that having a stock of parts on hand at the central facility was inefficient for two reasons. Firstly, the parts on hand at the central facility were of no use to a vehicle stranded elsewhere. Secondly, they were keeping their operational costs to a minimum by maintaining a minimal supply of inventory on the shelf. The two transit facilities using methanol engines recognized that their maintenance costs were appreciably higher than for diesel engines. This was a concern due to vehicle down time and employees being used for methanol engine repairs while other repair work had to be deferred.

G.4 Fuel Economy

Some managers were very concerned with this item; others ranked it as not overly important. Their concerns were primarily engine reliability and overall costs to keep the engines operating for their firm's expected engine life cycle. Volumes of fuel used often allowed the individual firms to tender for bulk fuel at competitive prices. Some firms consumed over 30,000,000 litres of diesel fuel annually. Managers who were cognizant of the costs of their operations recognized that fuel represented only around 20% of variable operating costs. When they considered total operational costs (variable plus fixed), fuel often represented only 10% to 15%.

Asked if they believed that methanol would be cheaper per litre than diesel, the responses from the managers were varied. There was general consensus that methanol, if it were to become a fuel in general usage, would be taxed and that the costs might end up being the same as diesel on a per litre basis. Most managers could not visualize using methanol in the future until some means of price stabilization was developed, and commercial actual costs of the fuel were known. One firm located in the Vancouver area indicated that it tried to purchase as much fuel as possible outside Vancouver to avoid the local tax surcharge on diesel fuel. Labour rates were the primary cost concern. Service personnel and drivers represented the preponderance of labour costs for virtually all companies. Some respondents, realizing that methanol only has about half the specific energy value of diesel fuel, indicated that for methanol to be truly competitive it would have to retail for less than half the price of diesel.

Managers were asked if they would consider switching to an alternative fuel such as methanol if they could reduce their fuel costs by 5 per cent. One manager stated he would switch for 5% after the engine technology had been proven. Three other managers said they would consider switching to an alternative fuel for a 5% savings if there were government subsidies for conversion. One manager stated that, because of the risk involved, he would not consider switching unless he could realize at least a 15% reduction in fuel cost.

G.5 Payback

All except one respondent indicated that they would require far more information about costs and payback before they would consider switching to methanol. The exception to this rule was the manager of a transit facility who had been operating two MILE methanol transit buses for an extended period of time and was about to take delivery of three new buses with methanol engines. The fleet has subsequently ordered three more buses with methanol engines. He had seen problems with the methanol engines in their infancy, but was now pleased with their performance. He thought that by purchasing vehicles now, he would be in a position to obtain governmental funding and be ready for emissions legislation expected within two to three years.

Many firms indicated that conversion to methanol would require governmental incentives, similar to those offered for propane and natural gas conversions.

G.6 Business Risk

The percentages of managers who felt that the business risk involved in switching to methanol fuel would be untenable rose from 63% in the first survey to 79% in the second survey. A major reason was the limited amount of information they had at their disposal at this time. They knew nothing of engine performance, engine reliability, market costs, volatility of methanol prices and availability of methanol as a fuel. There were too many "ifs" and "buts" to entertain the notion of converting to methanol at this time. One particular firm had had a very discouraging experience with propane. After deciding it no longer wanted to operate on propane, the trade-in allowance provided by the dealership was far lower than anticipated.

H. SOCIAL/ENVIRONMENTAL BARRIERS

H.1 Safety

The changes in perception of safety factors were dramatic between the first and final surveys. Initially, only one manager felt that methanol would be as safe as diesel in the garage. In the second survey, 70% felt that methanol would be as safe. Diesel was recognized by all managers as being the safest fuel. When not prompted, the respondents were sometimes unsure of what methanol really was. Questions such as "Is it a gas?" were fairly common. When advised that methanol was the liquid used as gas-line antifreeze the common knowledge of this product prompted a favorable response.

Most managers commented on the extreme safety of diesel fuel. One bus company manager said that even with the operation of the dynamometer and welding equipment in an indoor garage, diesel had never presented any safety problems. The same company was unhappy with propane because it perceived it to be unsafe in the maintenance garage.

One manager felt no fuel could be as safe as diesel in the garage. One of his buses caught fire and the entire bus burned. When the mechanics examined the bus after the fire, they discovered the only part to remain intact was the fuel tank, still full of diesel fuel.

When questioned about the safety of methanol on the road, 80% of managers in the initial survey felt that the two fuels would be equally as safe. In the second survey, almost all managers felt it would be. Again, two managers were unsure of whether methanol was a liquid or a gas. When advised it was a liquid, their verbal replies changed to a more positive attitude. Without the prompting, however, their answers were clearly negative towards methanol being as safe as diesel.

H.2 Emissions

When first surveyed, 86% of the managers felt that methanol engines would be superior to diesel engines in terms of exhaust emissions. This figure did not change as time went on; in the latter survey almost 80% felt the methanol engines would be superior.

Indoor air quality with diesel engines was recognized as being poorer than methanol. The answers, especially from the highway trucking fleet managers in the final survey, were tempered with statements such as, "We only run the engines when in the repair shop. And we use exhaust systems to carry the exhaust out of the shop, too. Our business is running trucks on the roads; not in the shop." These statements were true for firms that stored vehicles outdoors, but not for those that parked vehicles indoors, such as transit facilities. Starting vehicles indoors and warming the engines before service was objectionable to servicing crew and drivers. The managers were fully cognizant of the implications of diesel exhaust in an indoor environment.

Engine emissions were ranked last in importance to managers during the initial survey, behind purchase price, maintenance cost, safety, and fuel costs. In the second survey the managers were becoming increasingly aware of emissions, and 25% indicated that emissions were priority one when making an engine purchasing decision. One firm indicated that engine emissions was the absolute primary criterion when making a decision to purchase an engine. It wanted to have the lowest emissions in the vehicle storage area (indoors). It was also acutely aware of growing public awareness concerning exhaust smoke. A manager of a highway trucking fleet indicated that he was becoming more aware of the loss of air quality. Being a pilot, and flying to his firm's various locations, he had first hand knowledge of deterioration of the air quality in many areas of Canada. He indicated that "everyone thinks it's just California that has a problem; I can tell you that we've got a problem right here in Canada, too. In fact, one day last summer, my sources tell me that we had a higher smog count than Los Angeles has on its poorest days."

H.3 Lack Of Knowledge

Asked if they would switch part of their fleet to methanol today, all the managers in the first survey replied they would not. In the second survey, all but one manager, who is currently preparing for delivery of three new methanol buses and tendering for three more, again replied that they would not.

In every case where the managers indicated they would not, all stated the same thing: they did not have enough information at their disposal to make even an elementary business decision. Some of the respondents did not know, until advised, what methanol was. All were totally familiar with gasoline and diesel, one was knowledgeable about compressed natural gas, some were familiar with propane(generally through household barbecue usage). Only a few knew anything of any consequence about methanol or ethanol.

Some of the managers were familiar with proposed U.S. federal legislation and the transit managers were cognizant of emissions legislation that would affect their industry. Some managers indicated that they would consider trying an alternative fuel if they had more information about engine durability and reliability. All managers indicated that to take such a business risk without government assistance would be impossible.

When asked if they would like to find an alternative to diesel fuel, 60% of managers in the first surveyed mildly agreed. Only about 50% were receptive to this idea when questioned in the second survey. One particular firm wanted to have nothing to do with alternative fuels unless at least a 15% decrease in fuel costs could be realized with engine reliability equal to diesel. This manager had had a poor experience with propane and, as a result, was very reluctant to try any other fuel.

Only five of fifteen managers participating in the second survey requested a copy of the final Project MILE report. This was interesting because it was clearly indicated that the purpose of the second survey was to see if the transportation industry's perception of alternative fuels had changed in three years. After stating they had a lack of information, only about one-third asked for more.

I. CONCLUSIONS

Fifteen fleet managers were surveyed for comments in the following categories relative to commercialization of methanol:

- Technical
- Economic
- Social

The two surveys indicated that, except for the companies participating in MILE, little was known about the use of methanol. The questions asked by the managers about methanol and how it was used indicated that the transportation industry's knowledge of methanol as an alternative to diesel had changed minimally in three years.

To convert to an alternative fuel of any kind all managers indicated they would have to know much more than they did about several factors, the most important being engine reliability. Many of the fleet managers were somewhat willing to try an alternative fuel, provided they could be given more information about engine reliability, engine maintenance costs, fuel availability on a retail basis and some means of governmental assistance for converting to methanol.

Those aware of the environmental problems surrounding the use of diesel fuel communicated a sense of wanting to use an alternative fuel but with the proviso of "not me first". They wanted to know what had been learned by others in the transportation industry before committing themselves to try an alternative to diesel. With the transportation industry in a state of flux as far as deregulation and impending emissions standards, especially in the U.S., there was a feeling of sitting back and waiting to see what the others will do.

The greatest change in perception occurred in the area of emissions and what diesel engines do to the quality of the air we breathe. There were managers who recognized that their firm had, at some time, to assist in "cleaning up the air" for their children and generations to come. However, corporate bottom-line demands meant that they had to be cautious about business risks and not lose customers due to poor reliability of delivery of goods.

The capital cost of the methanol engines (assumed higher than their diesel counterparts) was not an overwhelming concern when choosing an engine. The need to have parts available throughout North America, warranty terms and engine reliability were far more important aspects of engine purchase decisions. Labour costs were a bigger on-going item than fuel costs. Fuel costs usually represented about 20% of any firm's overall cost of doing business. Only a few managers indicated that fuel costs presented a serious barrier to the use of alternative fuels. The basic concern was that methanol would have to be priced according to the loss of energy value compared to diesel. Only one or two managers indicated that they could envision paying slightly more for methanol (on an energy equivalency basis) to help clean up the world's air. If all transportation firms were required to "play on the same field", i.e., pay the same rates for fuel, they would be somewhat more receptive to the use of an alternative fuel.

Safety of methanol in an indoors environment is a subject of great concern to transit fleets in particular. No serious incidents occurred during the course of the project. All project vehicles were fuelled outdoors. Buses were maintained and parked indoors, trucks were parked outdoors. There is a need for an in-depth examination of indoor fuelling in conjunction with fire authorities, worker health and safety organizations, and equipment safety standard laboratories.

Before methanol can be considered as an alternative fuel, the transportation industry must be convinced of the following:

- methanol engines provide equal reliability to diesel engines.
- maintenance costs of methanol engines will not be any higher.
- methanol fuel must be readily available throughout North America.
- methanol fuel must be equivalent in price to diesel fuel on an energy content basis.

CHAPTER IX: CONCLUSIONS

A. STATE OF TECHNOLOGY

Every major international manufacturer of diesel engines has engaged in some methanol fuel research. Diesel engines do not adapt to alcohol fuels as readily as spark-ignition gasoline-type engines, and serious work on the subject began only around 10 years ago. The technology is relatively new and to date there is limited commonality between individual designs, and no clear indication of the "best" configuration for a methanol-fuelled compression ignition engine. Detroit Diesel Corporation will market a methanol bus engine in 1991, but many other manufacturers remain at the experimental level, waiting for a clear signal from the marketplace before committing resources too heavily.

At least six different methods of igniting methanol fuel in a diesel type engine have achieved prominence in research and testing work. They may be summarized as:

1. Glow-plugs - Provision of a continuous point source of heat to augment the heat generated by compression sufficiently to cause ignition of injected fuel.

2. Spark-plugs - A heavy-duty, high-energy single or multi-spark ignition system timed and fired similarly to a conventional spark ignition engine.

3. Scavenge Air Control - Unique to 2-stroke engines, in particular the Detroit Diesel design. Controls and maintains combustion heat by regulating air flow during inlet and exhaust phases.

4. Pilot or Dual Injection - Uses a small pilot charge of diesel injected before the main methanol charge to initiate combustion.

5. Fumigation - Introduction of methanol fuel by carburation into inlet manifold instead of by direct injection, for subsequent ignition by spark or glow plugs.

6. Fuel Additives - Use of a combustion enhancing additive which causes the methanol fuel to auto-ignite at a temperature similar to diesel. Often called "cetane improvers".

The foregoing is by no means an exhaustive list of all possible designs which have been proposed and tried out. It is intended to show that methanol Compression Ignition design has not yet matured, and will be subjected to more changes and refinements if a viable market appears.

It is possible to identify some probable fundamental trends. One of the most basic choices concerns the nature of the fuel to be used. There are three leading candidates:

1. 100% Methanol

2. Methanol blended with some proportion of hydrocarbons. The leading example being "M85", i.e., 85% methanol, 15% gasoline.

3. Methanol with ignition enhancer additive.

Most work with diesel type engines has been done using 100% methanol fuel, which probably is the most advantageous approach from an emissions point of view. It also implies simplicity of fuel supply arrangements.

The M85 blend fuel, has been widely used in gasoline type engines. It is helpful in achieving acceptable cold starting and offers a solution to the major safety questions raised in conjunction with methanol and vehicles, flame visibility and in-tank explosivity. However, when used in a diesel engine it degrades the emissions performance.

Introduction of ignition-enhancer additives into the methanol fuel implies a major change in philosophy. Simply put, this represents adapting the fuel to fit the engine instead of vice versa. It is a very attractive proposition, and diesel engines have been run on such mixtures with no modifications whatsoever. Obviously some work is required to bring power and performance up to diesel standards, but it is much less than that required to accommodate 100% methanol. The principal disadvantages involved are the effects on emissions, which are as yet far from fully explored, and the incremental cost of the additive.

At present 100% methanol is the preferred standard for diesel engines in USA and Canada, where reduction in exhaust emissions is the driving force behind any potential change in fuels. The introduction of 10% to 15% hydrocarbon content into the fuel seems unlikely to have anything other than an adverse effect upon emissions, particularly hydrocarbons and particulates. However, this point has not been extensively tested in practice, since few diesel engine builders and researchers have opted to use this blended type of fuel. Similarly, the case for ignition enhancer additives needs to be much more thoroughly explored before conclusions may be drawn. For instance, it has been proven that diesel engines will start and run on methanol fuel containing 1% or less of additive, whereas early testing used 5% to 7% levels. Clearly, it appears at first sight desirable to use a minimum percentage for economic reasons, but recent testing indicates that regulated emissions output may increase when the additive content is reduced below a certain level. How the balance of cost, emissions, cold starting and overall engine performance may settle is very far from being determined at the present time. Because there are only a handful of companies promoting these "cetane-enhancer" additives, and likewise very few manufacturers actively investigating their use, the pace of advance in this field is relatively slow.

A second major point of consensus at present is the need for some type of ignition assistance source to fire the methanol fuel under all operating conditions. At present the two leading candidates appear to be glow plugs and spark plugs. Even designers who have set auto-ignition as a target, the most prominent being Detroit Diesel, have found glow plugs necessary for cold starting and warm-up phases. Glow plugs and spark plugs represent incremental cost and complication over conventional diesel technology, both at initial equipment purchase and throughout vehicle life, because of increased maintenance costs.

B. VEHICLE PERFORMANCE

Vehicle performance is definitely an area in which methanol makes a very strong showing. Theoretically there is no reason why a methanol engine should be inferior in performance to an equal size diesel engine. In fact, because its potential torque output is not smoke limited, more power may be obtained from a methanol - fuelled unit. The project experience definitely supports this hypothesis, and there has never been any denial that the project engines gave excellent performance when operating properly.

Methanol is a viable replacement for diesel fuel in Canadian heavy duty vehicle fleets in the near and medium term from a technical point of view.

The project succeeded in its primary aim, that of demonstrating that methanol vehicles can be used by a fleet operator to carry out normal revenue earning tasks, with relatively little change from the use of diesel vehicles. Project vehicles have hauled goods and carried passengers over extended time periods with acceptable standards of performance, safety and reliability. The Caterpillar engine trucks matched diesel journey times on an 1,800km route, and covered 88% of the mileage achieved by diesel trucks in the same time frame. The Detroit Diesel buses began the project with many problems, but progressive development work improved virtually every aspect of their performance. The lessons learned contributed to DDC's pre-production program, which involved over 50 engines by 1990. The company has definite plans to bring a 6V-92 methanol engine into the marketplace for the 1991 model year. The Cummins engines also underwent successive improvements. They covered similar monthly mileages to comparative diesel units, and also demonstrated competitive energy consumption figures. The New York State section of the project showed that existing diesel engines can be converted to use additive enhanced methanol fuel with relatively little cost and complication.

Detroit Diesel Corporation remains the only manufacturer intending to sell methanol engines in Canada in the immediate future. However, DDC manufactures over 90% of the engines used in city transit buses and long distance coaches in this country and in the USA, so that methanol power for the bus and coach sector will in all probability be available within a year from the date of this report. Cummins and Caterpillar have no definite plans regarding marketing of methanol engines at present.

Equivalent reliability to diesel engines is not yet guaranteed, but standards are constantly improving and no mechanical problems appear to be insurmountable.

All of the methanol engines used in project MILE required considerably more maintenance and servicing efforts to keep them operational than the corresponding diesel engines. The original intention of studying comparative maintenance costs was frustrated by the amount of specialized attention and protracted periods of fault diagnosis required in the early stages of the project. At times buses were out of service for several weeks awaiting spare parts and repair advice. It became impossible to make a sensible comparison of maintenance requirements in monetary terms.

In more specific terms the Detroit Diesel engines were subject to numerous small problems during the first half of the project, many of which were not connected directly with methanol fuel. The electronic engine control system was unpredictable and hard to diagnose, and the blower air by-pass control, fuel pump, fuel pressure switch and glow plug control unit all were prone to failure. All of these matters were dealt with, most of them in Autumn 1988 when the engines were extensively upgraded. Eventually it became apparent that the greatest problem to be overcome with the DDC engines was premature fuel injector failure. During the project, average injector life was improved from 2,000km to 20,000km primarily by use of low-ash lubricating oil. DDC research into fuel and fuel systems has already revealed other modifications to improve life. Injectors have been operated in laboratory tests for extended periods beyond those achieved in the project, with no sign of failure.

Energy - based fuel consumption is not yet equivalent to diesel.

The energy content of diesel fuel oil is approximately 2.25 times as great as that of methanol on a volumetric basis, dependant upon the particular specification of the diesel under consideration. Most manufacturers took the achievement of energy consumption equal to the parent diesel unit as an acceptable goal for their methanol engines, and attained this goal during test bench development work. Of the three types of engine involved in the project, the Cummins units, using the Avocet/methanol fuel, came closest to getting equal energy consumption on the road. The overall methanol to diesel ratio for the Caterpillar trucks was 2.4 to 1, and for DDC engines in the buses 2.7 to 1.

No attempts to optimize fuel consumption were made in the project. The methanol vehicles all used similar transmission and axle ratios to the diesel control vehicles. The drivers were not advised to explore the low speed torque capabilities of the methanol engines, and could not in any case have done so with the Detroit Diesel and Cummins units, since the buses and garbage trucks had automatic transmissions. Engine modifications carried out were directed at improving reliability, idle quality or power output, but not fuel consumption.

The methanol vehicles carried inherent handicaps to fuel economy in comparison to the diesels, in the form of extra weight of fuel and extra electrical power requirements. For example, the Winnipeg buses carried a second fuel tank holding approximately 350 litres of fuel, representing a total additional weight (tank and fuel) of approximately 500kg. Methanol specific electrical components included the glow plugs and control system and the fuel pump and fuel cooler fans, representing a 3 to 4 bhp parasitic load on the engine. The Caterpillar trucks also carried extra fuel and required glow plug power.

The Cummins trucks did not have these handicaps. This was probably part of the reason for their superior energy consumption figures. The latest version of the Detroit Diesel engine eliminates glow plug operation except during starting and warm-up, and there is really no need for the fuel cooler fans to run continuously in average Canadian weather. Obviously there is much work to be done concerning the reduction of methanol fuel consumption, involving more than just engine development. During the project other needs overshadowed this important topic. There is no reason to suppose that it will not be effectively addressed as the evolution of heavy duty methanol power continues.

C. FLEET INFRASTRUCTURE IMPACTS

Methanol fuel is not as inherently safe as diesel, but proper personnel training and the use of appropriate equipment can provide accident free operations.

Methanol has very different physical properties to diesel fuel oil. For vehicle fuelling purposes, its overall characteristics are much closer to gasoline. This comparison was used during the project as a preliminary indication of the safety implications for fleets and other interested parties. The exact nature and comparison of methanol to diesel from a safety point of view has been exhaustively explored in many documents, including the safety section of the project manual. The conclusion given here is based on the fact no reported accidents of any consequence occurred during the period of project vehicle conversion and operation from January 1986 to September 1989.

New maintenance skills were required to keep the project vehicles operational, particularly regarding electronic technology, but the same applies to many modern diesel engines.

The maintenance requirements of the project vehicles were distinctive according to the type of engine used. The Cummins engines were really no different to a diesel with respect to the systems and components involved, equipment required and problem diagnosis and repair. For instance, adjustment of fuel pump calibration was achieved in exactly the same way as for a diesel unit, but the settings were different. Replacement of methanol compatible seals, gaskets or fuel lines was exactly the same as replacing the normal diesel type components. As the project advanced it became clear that full optimization for the "Avocet"/Methanol fuel might require more modifications to the engines. However, none of the changes envisaged would be likely to affect the maintenance or servicing procedures. (e.g., compression ratio, piston cooling arrangements, bearing materials etc.)

The Caterpillar engines introduced new components in the form of glow plugs and the associated control system. The control system voltage levels and output characteristics were checked at routine servicing intervals (250hrs). Occasional re-calibration was required, and the plugs were checked and changed if necessary.

At the start of the project, senior mechanics were picked from the dealer staff and trained to service and repair the methanol related systems. Full factory back-up was also provided on a 24 hr. basis to give advice and on the spot assistance. This proved to be an excellent arrangement and the dealership carried out all of the repair work on the trucks during the project without difficulty or undue delay. Engine maintenance procedures in all other respects were essentially unchanged by the conversion to methanol. The actual number of glow plugs changed and system tests and resets carried out would certainly be greatly reduced in any production version of the engine. It would also be possible to simplify the diagnostic and repair methods.

The Detroit Diesel engines entered the project as an unknown quantity to the maintenance staff at Winnipeg and Medicine Hat, principally because of the DDEC electronic control systems. The DDC methanol engines were the most complicated used in MILE, and carried in addition a number of external items such as electric fuel pumps, cooler fans and pressure switches not used on the other project engines. The "learning curve" for maintenance of these engines was much longer, but they came to be the only ones handled completely by fleet staff without specialist dealer assistance. Detroit Diesel Corporation provided regular information updates and training assistance as the fund of operational and maintenance experience with the engines increased.

A key element in the diagnosis of the DDC engines was a portable electronic system reader. This plugged into the engine system and provided coded output messages about the status of the engine operation. The most frequent use was the analysis of the fuel injector control signals, particularly pulse width, which indicated the injection duration time. Once service personnel had become familiar with the type of information available, they were able to analyze most operating problems with speed and accuracy. The second important quantity influencing engine performance was fuel system pressure, which was easily measured in an orthodox manner using a bourdon-tube gauge.

Winnipeg Transit received its first consignment of DDEC equipped diesel buses in 1988. Electronic control of diesel engines is steadily increasing and will certainly become the standard in the future, as has already happened for gasoline automobile engines. Maintenance of methanol and diesel engines will be similar in all but actual detail adjustments and settings. This is one advantage in comparison to gaseous fuelling, for which a knowledge of pressure vessels and special mechanic certification is required.

Fuel distribution and storage is not a problem with a dedicated system but may give trouble in an interim situation.

During the project the methanol fuel was handled just as it would be if adopted for use on a major scale. The supply originated at the plants of Canadian Oxygenated Fuels Association (COFA) members, principally Celanese Canada Inc., in Edmonton, and Alberta Gas Chemicals (Novacor) at Medicine Hat. Winnipeg Transit and Medicine Hat Transit deliveries were direct from plant to storage tank by road tanker truck. The City of Vancouver and Williams Moving & Storage base depot tank at Coquitam were supplied through an intermediate agency, Van Waters and Rogers Ltd., which received rail-car bulk loads of methanol, blended the additives required, and completed the local delivery in tanker trucks. Van Waters and Roger Ltd. is a major bulk chemical dealer with branches in several Canadian cities, and handles large quantities of methanol in the normal course of its business. The second Williams Moving and Storage tank at Sicamous received deliveries from the Medicine Hat Novacor plant in road tankers operated by Mohawk Oil Co. Ltd., with the requisite anti-corrosion additives blended in when the truck was loaded.

The bulk fuel tanks at each site were originally sized for deliveries once per month, but instances occurred in the early stages of the project where no deliveries were required for 6 months. The methanol fuel used in the project was therefore exposed to a representative variety of shipping, handling and storage situations. It is of interest to note that COFA shipped a test consignment of methanol through one of Canada's major pipelines during the project and detected no unacceptable contamination or deterioration in the "heart cut" at the receiving end.

There were very few fuel contamination problems during the project. The fleet experiences may be summarized as follows:

Winnipeg Transit: No problems beyond occasional vehicle filter changes.

Medicine Hat Transit: In summer 1989 chloride and hydrocarbon contamination were detected in the bulk storage tank. The tank was drained and cleaned out. Contamination was ascribed to an improperly cleaned delivery truck. Delivery arrangements were revised to use dedicated methanol trucks only.

Williams Moving and Storage: Persistent plugging of vehicle primary fuel filters during early stages of project. Eventually the problem disappeared by itself and was assumed to be due to sand and dirt left in the fuel tank and/or pipes by the contractor during the construction of the underground tank.

City of Vancouver: Confusion over fuel analysis results at start of project due to unknown effects of "Avocet" additive concentration. No other problems.

The fuel analysis program in the project dealt with three types of contaminant: water, non-volatile matter and chlorides. Water content was normally in the 100 to 200 ppm range, indicating that there was no tendency for the methanol fuel to absorb excessive amounts of water. It was assumed that the low levels of water contamination experienced would have little effect on the engines. Later in the project, Detroit Diesel Corporation research work produced results indicating that water content strongly influenced fuel injector life, and must be minimized.

Non-volatile matter was primarily insoluble dirt and grit. This was taken as the most significant indication of rusting of fuel storage tank interiors, corrosion of system components or presence of dust, construction residue, welding slag, etc. With the exception of the incident involving the Williams Moving and Storage vehicles, no particular problem arose from this quarter. It was hoped to arrange for some actual inspections of the storage tank interiors, but unfortunately the necessary explosion-proof lighting equipment was not available when inspection opportunities occurred. (E.g., during the cleaning of the Medicine Hat tank.)

To gain acceptance among fleet users, particularly bus fleets, methanol engines must demonstrate exhaust aldehyde outputs near to those of competitive diesel engines.

The most frequently highlighted concern regarding emission levels from methanol engines is the amount and effect of the aldehyde group compounds generated. The general perception of methanol heavy duty engines at present appears to be that CO, NOx and particulates can be reduced in comparison to diesel engines, but aldehyde emissions will be greater. Given the rapid pace of advance in diesel emissions reduction technology, and the constant improvements in methanol engines, it is almost impossible, and certainly limited in value, to attempt to make dogmatic statements regarding the relative aldehyde outputs of methanol and diesel engines. The problem with fleet perceptions is that aldehyde group chemicals are new names in the air pollution lexicon. They have not previously been regulated, but many people know that the most prominent constituent, formaldehyde, is widely recognized as harmful.

Early in the project people who had witnessed the pioneer North American methanol bus, Methanol 1, in operation in San Francisco spoke of a distinctive exhaust odour and stinging of the eyes caused by the fumes. Transit fleets, faced with the situation of starting large numbers of buses indoors every morning, are very sensitive about the exhaust gas emission and concentration levels in the working environment. Anyone who has ever been in a bus garage on a winter morning at start-up time can appreciate why this is so.

Personnel involved are naturally apprehensive about the effects of something largely new and unknown. (It is not at first generally understood that formaldehyde is also present in diesel fumes). The worst immediately noticeable effects of methanol exhaust (i.e., eye and nose irritation) are most often caused by the presence of unburned fuel under transient operating conditions such as cold starting. However, it is only partly useful to point out that these situations are temporary and represent only a small percentage of normal operating time, especially when the critical cold starting condition occurs in the most inconvenient location at the worst time.

Methanol engines must be expected to receive harsh criticism from potential users about their exhaust emission characteristics, because they are represented as the potential answer to heavy vehicle pollution problems. Operators see methanol fuelling as a means to improving air quality, but when they learn that the output of some emission products actually increases, their willingness to accept the new fuel drops considerably. If the aldehyde output from methanol heavy duty engines could be reduced to equal typical diesel levels the misgivings and controversy would disappear.

Project MILE attempted to investigate the situation of relative aldehyde emission levels in the working situation. The portable test apparatus did not provide a sufficient degree of sophistication to make comparisons with sufficient reliability and accuracy to satisfy fleet users. In any case, it was directed at answering only part of the question. Information regarding acceptable ambient concentrations of aldehydes and methods of measuring the same are also incomplete and unproven at the present time.

D. COSTS AND BENEFITS

Methanol produced for the transportation market can be economically competitive at higher crude oil and diesel fuel prices.

With existing fuel prices, methanol cannot be considered cost competitive with current diesel engines. Methanol fuel costs are the single largest component of the extra costs for methanol in large engines. However, methanol is currently produced for chemical markets. A more likely scenario would be methanol plants built specifically for the transportation market, with pipeline distribution to major markets. It is also likely that the cost of diesel technology will increase to meet more stringent emissions standards. Under this scenario, methanol is economically competitive at crude oil prices of $20 to $27 US per barrel depending on bus or truck application.

Methanol promises definite environmental benefits.

Methanol engines have been shown to meet the stringent 1991 U.S. regulations for bus applications. It is not clear or certain that diesel engines will be able to meet these standards. Not only do methanol engines meet the standards but they also significantly reduce nitrous oxides and particulate emissions, relative to the standard and today's diesel engines.

Nitrous oxides are a major constituent of urban smog and ozone. Vehicle particulates have been directly linked to cancer and human respiratory diseases. Methanol engines with the use of a catalyst can produce significant reductions in carbon monoxide emissions compared with the regulations. The use of methanol will help to alleviate these air quality problems, especially in urban areas where transit buses are concentrated and where the problems are most acute.